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MEMORANDUM

TO: Members, Washington Academy of Sciences
FROM: The Editors of the Journal
SUBJECT: Call for Papers

As the Journal begins a new volume, the editors are pleased to announce some welcome changes. First, we invite the submittal of articles and papers from the scientific community for publication in the Journal. Whereas past issues have focussed primarily on technical issues of the physical sciences, we would welcome contributions from the many disciplines represented by the societies affiliated with the Academy. Papers from members should fall into one or more of the following areas:

— An historical perspective of an area.
— Current status or general review of a subject.
— New research results.
— An editorial or commentary.
— News, announcements, letters.

While we have published thematic issues in the biological sciences, the editors would be pleased to set aside selected issues for the publication of other subject areas as well.

In addition, beginning with this issue, the Journal will include a Commentary section to include editorial comments and responses to the materials presented in the Journal. For this issue, we have included a Commentary originally appearing in *New England Business,* concerning the role of the liberal arts in business.

At the present time, publication time is about 3 months. All papers may be subject to regular review procedures at the discretion of the Editors. A copy of the "Instructions to Contributors" is included in each issue. If there are any questions, please contact the Editors.

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Commentary

WHY BUSINESS NEEDS THE LIBERAL ARTS

The exemplary partnership between business and education in Massachusetts was recently emphasized by a one-day conference, "Striving for Excellence," co-sponsored by U.S. Sen. Paul Tsongas and the New England Council.

Throughout the day, many forward-looking professionals from both sectors expressed their concern about the need for further improving the business-educational relationship in Massachusetts to meet the domestic and international challenges of the next 20 years.

Speakers and panelists made many sincere remarks about business education, computer training and literacy, finance and accounting knowledge and the physical sciences. But there was precious little mention, despite addresses by Gov. Michael S. Dukakis and other notables, of the liberal arts, the social sciences and the tradition the humanities play in developing clear thinking, ethical judgment, expository writing skills, evaluation, the disciplines of inductive and deductive reasoning, creative problem-solving, and the ability to take disparate elements from many apparently isolated administrative and technical specialties and relate them to one another.

There was also seldom any mention of the part that the humanities, liberal arts and social sciences can play in the international sector, where so much of our business acumen and profitability in the next 20 years will count. As Harvard University President Derek Bok has noted, "The critical problems lie in how business can accommodate itself to larger public concerns expressed by legislatures, government agencies and community groups," including international constituencies.

Today's leaders—and more importantly, the leaders of tomorrow—will profit greatly from acquiring and improving international negotiating skills, human relations and communicative skills, and the ability to foster creative problem-solving and entrepreneurship. But with so many of these skills currently lacking or needing improvement, we must ask ourselves where this training will come from. Ideally, such training has come from our colleges and universities, and increasingly our state university systems must play the major role here.

Today, however, we have in the commonwealth, as in many other states, what can be called the aging of the professions. A *Fortune* magazine story noted that MBA graduates are in trouble. They're searching for jobs and opportunities that don't exist. They know that their professional forbears, now in their mid-30s to 40s, have taken their place on the career ladder, and unless they decide to go into business for themselves will seldom vacate the posts they have worked so hard to acquire.

This means we must motivate millions of new, young, potentially enthusiastic employees facing the rigors of a new age with demographic statistics against them. Today's pressures to get a good job, study for grades and not the love of learning, choose careers not out of committed interest but for practical reasons, all tend to limit the focus of our students, limit risk-taking and generally impoverish the pool of exceptional talent we need to revitalize business.

The business schools have just now begun to include more liberal arts courses in their curriculums because of complaints from companies about MBA performance. Essentially, though, the liberal arts have been devalued to the point that attrition among the professional teaching ranks in these areas will take 10 to 20 years to bolster. Unfortunately, we need leaders *today* to solve the problems of remaining competitive tomorrow.

Although many managers and business leaders can define objectives and command employees, it is the unusual and gifted manager who can be called truly visionary, especially where motivating today's young professionals is concerned. Because we are now living, as Peter F. Drucker says, in "turbulent times," it is precisely the skilled, visionary leader we need to assure the costs of doing business tomorrow. Such leaders have an instinctual ability to see the big picture, to plan strategically, to coordinate, to network new arrangements in a changing world—to be, in a word, innovative: technically, organizationally, cross-culturally. But instinct alone cannot help us weather the storm. If we fail to provide both education and a continuity of professional experience for our younger managers and aspiring leaders, our international influence will falter.

We are at a watershed in our educational history. President Reagan's bipartisan commission report on education, *A Nation at Risk,* and a dozen other similar studies have shown that. What we choose to implement today for the next 20 years—because of our can-do attitude—will determine to a great degree nationally, and more important internationally, our success in an increasingly hostile, confusing and complex world.

To insure security for ourselves and our future demands a scrutinizing look at our country's current and future educational needs. At this critical juncture, before setting an inflexible policy that excludes the liberal arts, business and government and educational leaders need to re-evaluate how the liberal arts tradition can significantly contribute to a strengthened economy.

Richard Sawyer is president of Richard Sawyer Associates, a management and communications consulting firm in Weston, Mass. Copyright 1984. Reprinted with permission by the author and NEW ENGLAND BUSINESS.

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Effects of Dietary Protein on Lipid Metabolism in Rats

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ABSTRACT

The influence of animal and vegetable proteins on experimental atherosclerosis and cholesterol metabolism have been the subject of vigorous research in recent years. Carroll and Hamilton (1) demonstrated the range of effects exerted by different animal and vegetable proteins on cholesterol levels in rabbits. We have demonstrated that the effect of animal or vegetable proteins on experimental atherosclerosis can be mediated by the type of fiber in the diet (2). We have attributed part of the difference between casein and soy protein to the different ratios of lysine to arginine present in these proteins and have shown that lysine enhances the atherogenicity of soy protein and arginine exhibits the atherogenicity of casein (3, 4). Recently we have shown that a straight line is obtained ($r = 0.9979$; $p < 0.05$) when the average atherosclerosis established in rabbits fed fish protein, casein or milk protein is plotted against the ratios of lysine to arginine present in those proteins (5).

The effect of diets containing various proteins on lipid metabolism in rats is the subject of the ensuing discussion.

Materials and Methods

Male Wistar rats were used throughout. They were maintained in individual cages in an air-conditioned room and kept on a 12-hour light-dark cycle. The rats had *ad libitum* access to food and water. Rats were fed a basal semi-purified diet consisting of 40% sucrose (41.5% of calories), 25% protein (25.9 of calories), 14% coconut oil (32.6% of calories), 15% cellulose, 5% AIN salt mix and 1% AIN vitamin mix. Each experiment was of a 21-day duration. At the end of each study, rats were fasted overnight, weighed, killed by decapitation and serum and liver analyzed for total cholesterol (6), triglycerides (7), phospholipids (8) and protein (9). Levels of liver microsomal HMG CoA-reductase (10) and cholesterol 7 α-hydroxylase (11, 12) were also determined. To measure absorption, rats were given 0.5 mCi of [4-^{14}C]cholesterol 3 days before termination of the experiment. Feces were collected daily, pooled and the neutral and acidic steroids extracted, separated and assayed for radioactivity (13).

Data are presented as mean values

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Table 1—Influence of Lysine or Arginine on Lipid Metabolism in Rats Fed 25% Protein*

	Group†			
	CASEIN	SOY	CAS-ARG	SOY-LYS
Weight gain, g	176 ± 10	185 ± 5	184 ± 6	182 ± 8
Liver weight, g‡	9.6 ± 0.3	8.8 ± 0.3	9.5 ± 0.3	9.0 ± 0.2
Relative liver weight, %	2.91 ± 0.11a	2.58 ± 0.04ab	2.79 ± 0.06b	2.07 ± 0.05
Serum				
Cholesterol mg/dl‡	71 ± 9	64 ± 6	57 ± 5	62 ± 5
Triglyceride, mg/dl	48 ± 4	42 ± 6	48 ± 5	56 ± 8
Phospholipid, mg/dl	86 ± 3	84 ± 2	78 ± 1	84 ± 2
Protein, g/dl‡	4.33 ± 0.17c	4.45 ± 0.24	4.74 ± 0.06cd	4.47 ± 0.09d
Liver				
Cholesterol, g/100g	0.26 ± 0.02	0.25 ± 0.02	0.26 ± 0.02	0.29 ± 0.02
Triglyceride, g/100g‡	1.69 ± 0.14ef	1.23 ± 0.10e	0.99 ± 0.11f	1.32 ± 0.18
Phospholipid, g/100g‡	2.01 ± 0.13	2.07 ± 0.10	2.00 ± 0.07	2.17 ± 0.09
Protein, g/100g	19.1 ± 0.2	18.4 ± 0.6	18.2 ± 0.4g	19.4 ± 0.3

*Twelve rats/group fed 21 days.

†CAS-ARG, 23.9% casein plus 1.1% arginine; SOY-LYS, 22.9% soy plus 2.1% lysine. Diets contain: 25% protein; 40% sucrose; 14% coconut oil; 15% cellulose. Values bearing same letter are significantly different ($p < 0.05$) by *t*-test.

‡Significantly different by analysis of variance.

±SEM. Statistical analysis was carried out by ANOVA (14) or *t*-test (14).

Results and Discussion

The results of the first experiment are summarized in Table 1.

Addition of arginine to casein lowered serum cholesterol levels by 20%; lysine had no effect when added to soy protein. Liver cholesterol levels were unaffected by dietary protein, but liver triglycerides in rats fed casein were higher than they were in the other three groups. Levels of hepatic HMG-CoA reductase were affected by diet being lowest in rats fed casein and lowest in those fed soy protein. Addition of arginine to casein increased HMG-CoA reductase activity by 67% and addition of lysine to soy protein reduced it by 17% (Table 2). Cholesterol absorption was not significantly affected.

We have compared in rabbits the atherogenic effects of beef protein, casein, textured vegetable protein (TVP) and a 1:1 mixture of beef protein and TVP. Casein and beef were equally hypercholesterolemic and atherogenic. Dilution of the beef with TVP resulted in diets no more lipidemic or atherogenic than those containing only TVP (15). We studied similar diets in rats. Because the beef protein was dehydrated but not defatted, all test diets contained tallow rather than coconut oil. In this study

Table 2—Influence of Lysine or Arginine on Hepatic Enzymes of Rats Fed 25% Protein* (Six Per Group)

	Enzyme Activity	
Group	HMG-CoA Reductase (nmol/30 min/mg protein)	Cholesterol 7 α-Hydroxylase (pmol/min/mg protein)
Casein	0.39 ± 0.07ab	2.70 ± 0.55
Soy Protein	0.74 ± 0.13a	3.40 ± 0.64
Casein-Arginine	0.65 ± 0.11b	5.24 ± 1.25
Soy-Lysine	0.62 ± 0.17	4.95 ± 0.86

*Values bearing same letter are significantly ($p < 0.05$) different.

Table 3—Composition (%) of Diets used in Protein Experiments

	Diets*					
	BEEF (B)	TVP	BSF	BTVP	CAS-T	CAS-C
Protein						
Beef	25	—	22.8	12.5	—	—
TVP	—	25	—	12.5	—	—
Spent Flakes	—	—	2.2	—	—	—
Casein	—	—	—	—		
Fat						
Beef	4.7	—	4.2	2.3	—	—
Beef Tallow	9.3	14	9.8	11.7	14	—
Coconut Oil	—	—	—	—	—	14
Carbohydrates						
Sucrose	40	33.6	39.4	36.8	40	40
TVP	—	6.4	—	3.2	—	—
Spent Flakes	—	—	0.6	—	—	—
Fiber						
Cellulose	15	4.5	4.5	9.8	15	15
TVP	—	10.5	—	5.2	—	—
Spent Flakes	—	—	10.5	—	—	—

*TVP-Textured Vegetable Protein; BSF-Beef plus 14.2% soy insolubles (Spent Flakes); BTVP-Beef-TVP (1:1); CAS-T-Casein plus Tallow; CAS-C-Casein plus Coconut Oil. All diets contain 5% salt mix and 1% vitamin mix.

we added a casein-coconut oil group. The diets are described in Table 3.

The results (Table 4) show that the only significant difference in serum lipids is in the phospholipid levels, but that all liver lipid parameters are significant different by analysis of variance. The highest liver cholesterol and triglyceride levels were observed in the rats fed casein and tallow. The results from rats fed casein and tallow were surprisingly similar to those from rats fed casein and coconut oil. The protein is the determining factor.

The diets did not significantly affect hepatic cholesterol 7 α-hydroxylase, although the highest activity was present in the rats fed diet BSF, which contained the highest level of fiber other than cellulose. Hepatic HMG-CoA reductase activity was lowest in rats fed beef protein or beef-TVP 1:1; highest activity was observed in rats fed casein plus tallow (Table 5). Cholesterol absorption ranged from 53% (beef) to 69% (casein-tallow). The differences among the six groups were significantly different by analysis of variance ($p < 0.01$).

Huff *et al.* (16) had tested varying mixtures of casein and soy protein in rabbits and found that a 1:1 mixture did not elevate cholesterol levels and a 3:1 mixture gave cholesterol levels intermediate between those of 100% casein or 100% soy protein. We tested similar mixes of casein and soy protein in rats using beef protein and TVP as the proteins and tallow as the fat. As can be seen from Tables 6 and 7, the 1:1 mixture gave the highest cholesterol levels which were significantly higher than those of rats fed TVP: beef 1:3 or 100% beef protein. There were no differences in liver lipid levels. Rats fed TVP/beef protein 3:1 exhibited significantly higher levels of cholesterol 7 α-hydroxylase than the other four groups.

In a final study we compared the effects of 25% casein, fish protein, whole milk protein and beef protein (Table 8). Their lysine/arginine ratios are: fish protein—1.44; beef protein—1.60; casein—1.89; and whole milk protein—2.44.

Weight gains were significantly different by analysis of variance as were serum cholesterol and protein levels. Serum cholesterol levels in rats fed fish protein (37 ± 3 mg/dl) were significantly lower than in the other groups. Serum triglyceride levels in

Table 4—Influence of Dietary Protein on Lipid Metabolism in Rats*

	Group					
	BEEF (B)	TVP	BSF	BTVP	CAS-T	CAS-C
Weight gain, g	176 ± 4	168 ± 4	179 ± 7	190 ± 9	172 ± 5	172 ± 6
Liver weight, g	9.4 ± 0.3	9.0 ± 0.4	9.2 ± 0.6	9.9 ± 0.6	8.7 ± 0.3	8.9 ± 0.3
Relative liver weight, %‡	2.93 ± 0.07	2.88 ± 0.08	2.82 ± 0.14	2.93 ± 0.11	2.74 ± 0.06	2.82 ± 0.08
Serum Cholesterol, mg/dl	98 ± 5	96 ± 7	91 ± 4	87 ± 4	98 ± 8	95 ± 6
Triglyceride, mg/dl	41 ± 4	51 ± 7	38 ± 3	44 ± 6	40 ± 3	44 ± 7
Phospholipid, mg/dl‡	227 ± 11	223 ± 9	223 ± 12	211 ± 10	240 ± 9	226 ± 10
Protein, g/dl‡	4.92 ± 0.10	5.12 ± 0.13	5.44 ± 0.11	5.09 ± 0.19	5.21 ± 0.12	5.29 ± 0.11
Liver Cholesterol, g/100g	0.36 ± 0.02	0.39 ± 0.02	0.39 ± 0.03	0.46 ± 0.02	0.47 ± 0.02	0.38 ± 0.02
Triglyceride, g/100g‡	0.40 ± 0.01	0.53 ± 0.05	0.40 ± 0.04	0.51 ± 0.04	0.70 ± 0.07	0.45 ± 0.05
Phospholipid, g/100g‡	2.61 ± 0.07	2.68 ± 0.09	2.44 ± 0.07	2.45 ± 0.10	2.39 ± 0.13	2.57 ± 0.10

* Twelve rats per group: fed 3 weeks. Liver protein analysis on 6 liver per group.
‡ Significantly different by analysis of variance.

Table 5—Influence of Dietary Protein on Hepatic Enzymes in Rats* (Average of 6 Animals)

	Enzyme Activity	
Dietary Group	HMG-CoA Reductase (nmol/30 min/mg protein)	Cholesterol 7 α-Hydroxylase (pmol/min/mg protein)
BEEF (B)	0.43 ± 0.10ab	1.79 ± 0.32
TVP	0.86 ± 0.12ac	1.77 ± 0.37
BSF	0.81 ± 0.19d	2.66 ± 0.34
BTVP	0.28 ± 0.06cdef	2.23 ± 0.75
CAS-T	1.01 ± 0.15beg	2.35 ± 0.32
CAS-C	0.61 ± 0.08fg	2.39 ± 0.42

* Values bearing same letter are significantly different by *t*-test.

rats fed beef or casein (60 mg/dl) were lower than in rats fed fish or milk protein (42 mg/dl). There were no significant differences in liver cholesterol or triglyceride levels. Cholesterol absorption (% of a single dose of [4-^{14}C]cholesterol) was: casein, 60; fish protein, 61; milk protein, 55; and beef protein, 53.

The results of the four experiments are not strictly comparable since we used different sources of vegetable protein and fat. In the first study (Tables 1 and 2) rats fed casein exhibited the highest serum cholesterol levels and liver triglyceride levels. Microsomes prepared from livers of soy protein-fed rats showed the highest HMG-ColA reductase activity and those from casein-fed rats the lowest. Addition of arginine to casein or lysine to soy protein gave intermediate values. In the second experiment (Tables 3–5) we used textured vegetable protein (which contains some nonnutritive fiber) and beef tallow. Rats fed casein plus tallow showed highest levels of liver lipids. Hepatic cholesterol 7 α-hydroxylase activity was similar in all dietary groups. HMG-CoA reductase activity was lowest in rats fed beef-TVP 1:1 and those fed beef. In this experiment the type of fat present in the diet influenced HMG-CoA reductase activity, which was significantly higher in rats fed casein-beef tallow than in those fed casein-coconut oil. In the third study (Tables 6 and 7) we compared the effects of various ratios of beef protein and TVP. Rats fed TVP:beef protein 3:1 had the highest levels of serum triglycerides and high hepatic cholesterol 7 α-hydroxylase activity. HMG-CoA reductase activity was lowest in rats fed beef protein. There were no differences in liver lipids. The last experiment (Table 8) showed fish protein to be much less cholesterolemic than casein, whole milk protein or beef. Triglyceride levels were highest in rats fed beef or casein. No differences were observed in liver lipid levels.

Reiser *et al.* (17) found HMG-CoA reductase activity in rats fed casein to be significantly lower than in rats fed soy protein. Nagata *et al.* (18) made a similar observation and also observed that when mixtures of amino acids resembling casein or soy protein composition were fed the effect was reversed, i.e., the rats fed casein amino acids showed significantly higher HMG-CoA reductase activity. Rats fed either casein or the amino acid mixture of casein had significantly higher cholesterol levels than those fed soy protein or its amino acids.

Sugano *et al.* (19) reported that rats fed casein exhibited higher cholesterol levels than those fed soy protein. Adding enough arginine to the casein to give the lysine/arginine ratio of soy protein did not affect cholesterolemia, nor did adding lysine to soy protein. Rats fed casein had higher plasma insulin levels than those fed soy protein, but their plasma glycagon levels were similar. Addition of arginine to casein raised both plasma insulin and glucagon levels; addition of lysine to soy protein had little effect on either plasma insulin or glu-

Table 6—Influence of Varying Ratios of BEEF (B) and Textured Vegetable Protein (TVP) on Lipid Metabolism in Rats*

	Group (TVP/B)				
	100:0	75:25	50:50	25:75	0:100
Weight gain, g	79 ± 4	83 ± 9	81 ± 6	78 ± 14	76 ± 6
Liver weight, g	8.2 ± 0.5	8.8 ± 0.5	8.4 ± 0.2	8.3 ± 0.6	8.2 ± 0.3
Relative liver weight, %	2.80 ± 0.13	2.94 ± 0.08	2.85 ± 0.06	2.84 ± 0.04	2.86 ± 0.07
Serum Cholesterol, mg/dl	58 ± 7	68 ± 16	75 ± 7	51 ± 6	43 ± 5
Triglycerides, mg/dl	24 ± 3	37 ± 2	24 ± 3	33 ± 3	33 ± 3
Phospholipids, mg/dl	94 ± 5	112 ± 6	120 ± 6	100 ± 7	107 ± 5
Protein, g/d	5.27 ± 0.16	5.43 ± 0.19	5.47 ± 0.18	5.06 ± 0.21	5.07 ± 0.14

*Rats fed diets for 21 days.

Table 7—Influence of Varying Ratios of BEEF (B) and Textured Vegetable Protein (TVP) on Liver Lipid Metabolism in Rats*

	Group (TVP/B)				
	100:0	75:25	50:50	25:75	0:100
Liver Cholesterol, g/100g	0.28 ± 0.02	0.28 ± 0.02	0.30 ± 0.02	0.31 ± 0.02	0.31 ± 0.01
Triglycerides, g/100g	0.50 ± 0.01	0.43 ± 0.06	0.45 ± 0.08	0.48 ± 0.08	0.45 ± 0.05
Phospholipids, g/100g	0.21 ± 0.01	0.22 ± 0.01	0.21 ± 0.01	0.22 ± 0.01	0.23 ± 0.01
Protein, g/100g	20.8 ± 1.38	21.5 ± 0.92	17.6 ± 1.56	19.4 ± 0.69	18.5 ± 0.98
Liver Enzymes					
HMG-CoA Reductase	0.58 ± 0.06	0.51 ± 0.09	0.48 ± 0.13	0.45 ± 0.09	0.44 ± 0.08
Cholesterol 7 α-Hydroxylase	12.83 ± 1.57	23.08 ± 4.51	11.31 ± 1.01	10.00 ± 2.82	8.97 ± 2.01

*Rats fed diets for 21 days.

Table 8—Influence of Protein on Liver Lipid Metabolism in Rats (10/Group; Fed 21 Days)

	Protein			
	Casein	Fish	Milk	Beef
Weight gain, g*	77 ± 9a	95 ± 7	78 ± 7b	109 ± 5ab
Liver weight, g	8.6 ± 0.4	8.8 ± 0.6	8.8 ± 0.6	8.9 ± 0.2
Relative liver weight, %	3.09 ± 0.09c	2.94 ± 0.13	3.20 ± 0.29	2.87 ± 0.05c
Serum				
Cholesterol, mg/dl*	54 ± 6d	37 ± 3def	54 ± 5e	53 ± 2f
Triglyceride, mg/dl	60 ± 6gh	42 ± 6g	42 ± 4h	62 ± 10
Protein, g/dl*	3.90 ± 0.11ij	4.12 ± 0.06kl	4.63 ± 0.10ik	4.45 ± 0.10jl
Liver				
Cholesterol, g/100g	0.32 ± 0.04	0.27 ± 0.02	0.35 ± 0.03	0.32 ± 0.03
Triglyceride, g/100g	1.23 ± 0.24	1.11 ± 0.14	1.20 ± 0.15	1.15 ± 0.05
Protein, g/100g	18.50 ± 1.53	18.96 ± 0.50	20.66 ± 0.88	19.81 ± 0.52

Values bearing same letter are significantly different ($p < 0.05$) by *t*-test.
*Significantly different ($p < 0.05$) by analysis of variance.

cagon. The hypocholesterolemic effect of soy protein in man has been attributed to an effect on insulin and glucagon levels (20).

Summary

A comparison of the effects of animal and vegetable protein on cholesterol metabolism in rats has shown that animal protein (casein or beef) is more cholesterolemic than soy protein isolate or textured vegetable protein. Hepatic HMG-CoA reductase activity is generally lower in rats fed animal protein but there appears to be no influence on hepatic cholesterol 7 α-hydroxylase.

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Phenamethazine Sulfate Interaction with Triton X-100 Solubilized Succinic Dehydrogenase

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ABSTRACT

A novel solubilization of succinate dehydrogenase has been employed and the interactions between the enzyme and phenazine methosulfate (PMS) studied. The enzyme can be solubilized in the absence of exogenous succinate with a high concentration of Triton X-100 and apparently still yield a fully active soluble enzyme.

The effect of PMS is observed to be biphasic and appears to act as a positive modulator at low concentrations but is inhibitory at higher concentrations. PMS altered both V_{max} and K_m for succinate. The effect is less over the lower, activating range of PMS concentrations than over the inhibitory range.

A Hill Equation analysis has shown the enzyme to possess a minimum of three binding sites for PMS. At low concentrations of the dye, the Hill Coefficient is 1.99; in the inhibitory range of concentrations, the Hill Coefficient increases to 2.86.

It is suggested there is cooperativity between SDH and PMS at the low concentrations of PMS and that the enzyme can be activated by the binding of PMS at a regulatory site. At the

inhibitory concentrations the binding of a third molecule of PMS causes sufficient configurational change to bring about an increase in K_m decrease in V_{max}.

Introduction

In the course of our studies on changes in the enzyme properties during thermal acclimation by rainbow trout, we have examined the properties of succinate dehydrogenase (EC 1.3.99.1), SDH. In order to study this enzyme, the artificial electron acceptor system phenazine methosulfate (PMS) and 2, 6-dichlorophenol indophenol (DCIP) introduced by Ells (1) was used. Furthermore, it has been shown that the activity using artificial receptors was dependent on the preparative procedures (2,3,4). While there are several methods employed in the solubilization of SDH (5,6,7), the procedures are not entirely equivalent.

This report concerns the use of Triton X-100 as an alternate method for the solubilization of SDH which has certain advantages over those already in use.

Materials and Methods

Isolation of Mitochondria. Rainbow trout (*Salmo gairdneri*) were obtained from the Eastern States Federal Fish Disease Laboratory and Hatchery at Leetown, West Virginia. They were sacrificed by decapitation and the lateral muscle mass from three fish combined. Mitochondria were isolated according to Ernster and Nordenbrand (8) with the modification that EGTA was used in place of EDTA and ATP was added only just prior to use. The mitochondria could be stored (at −98°C under N_2 in 0.1 M borate buffer, pH 7.8, at 40–50 mg protein per ml, as estimated by ultraviolet absorption) for at least six days without loss in activity.

Assay Procedure. Prior to assay, the mitochondria were thawed at 25°C in a water bath and Triton X-100 added at 5 μl/mg mitochondrial protein. This suspension was allowed to stand at room temperature for 15 min with occasional, gentle agitation, and then centrifuged at 15,000 g for 10 minutes at 0°C. The supernatant fluid was carefully decanted and placed on ice for the duration of the assay procedure. Protein concentration was determined by Biuret reaction (9). The reaction mixture was composed of the following: 2.0 ml 75mM borate buffer, pH 8.2; 0.3 ml 3% BSA; 0.1 ml 50 mM KCN; 0.2 ml sodium succinate, varying from 0.13–8.33 mM, pH 8.2. The reaction was initiated by the sequential addition of 0.1 ml enzyme preparation (0.5–1.0 mg protein), 0.1 ml 1.5 mM DCIP and finally 0.2 ml of various concentrations of PMS. The mixture wax mixed by inversion, and the course of the reaction followed at 600 nm. PMS solutions were stored at −20°C for up to three days, and once thawed, used for no longer than three hours while maintained on ice.

Activity Determination. Specific activity is defined as production of reduced DCIP, in nmoles per minute per mg protein. Because there is a broad range of reported values for the molar absorption coefficient of DCIP ($16.1 - 21.0 \times 10^3$ M^{-1}), and the reported variability in commercial preparations (10,11) as well as the very substantial pH dependence of the absorption coefficient of the dye (11), the value was determined under the conditions of assay and found to be 17.5×10^3 $M^{-1}cm^{-1}$.

Data Analysis. The calculations to determine activities, kinetic parameters and statistical analyses were combined into a single program, written in Fortran IV, G Level. The values reported derive from weighted (by the reciprocal standard deviation) regressions of plots of 1/v versus 1/S. Correlation coefficients were calculated and the value of p determined from a Table of r (12). Because of the high levels of substrate-independent activity (13), the pro-

Table 1[a].—The Effect of the Triton/Protein Ratio on SDH Activity

Triton X-100 added, μl/mg protein	Activity, nMoles-min^{-1}-mg^{-1}
0.2	3.56 ± .36
1.0	4.15 ± .54
2.0	5.00 ± .19
5.0	5.51 ± .18
10.0	3.30 ± .32

[a]Triton X-100 was added to mitochondria at the indicated ratio of detergent to mitochondrial protein, and allowed to stand at room temperature for 15-20 minutes. The mixture was centrifuged at 15,000 xg for 10 min, at 2°C. The supernatant fluid was decanted and placed on ice, with an aliquot reserved for Biuret determination. The assay procedure as described in the text was followed using a PMS concentration of 1 mM and a succinate concentration of 2 mM. The activity is the corrected mean of three assays (succinate-dependent minus succinate-free activities) ± the standard deviation. See text for further details.

gram was designed to determine baseline activity from succinate-free assays and subtract this activity from succinate-stimulated activities prior to their use in the determination of kinetic parameters.

Materials. EGTA, tris base and HCl, ATP, disodium succinate, DCIP, PMS and BSA (fraction V powder) Triton X-100; nitrogen (Ultra-high purity and Oil-Free) and all other reagents were at reagent grade or better. Centrifugation was performed in an IEC Model B 20 refrigerated centrifuge. Assays were carried out using a Beckman Model DB-G spectrophotometer with scale expander and five-inch recorder.

Results

The Effect of Triton X-100 on SDH Activity

From the data given in Table 1 it appears that a broad optimum ratio of detergent to mitochondrial protein exists. The activity appears to plateau between 2 and 5 μl detergent/mg protein. The data presented in Table 2 show several aspects of Triton solubilization. First. disruption of the mitochondrial membrane system by rapid freeze-thawing prior to solubilization has no effect on the activity of the Triton-solubilized SDH. Second, simple addition of the detergent to the mitochondrial suspension produces a 45% inhibition of SDH activity. Third, centrifugation following addition of detergent results in localization of essentially all activity in the supernatant fluid (96–98% for 10, 15 or 30,000 xg for 10 minutes) at the same specific activity as the untreated mitochondria. The inhibition noted upon addition of Triton (Table 2) was somewhat less than that usually observed for other solubilization procedures.

The data presented in Figure 1 demonstrate the biphasic effect of PMS concentration on the observed SDH activity. It should be observed that for the data pre-

Table 2[a].—The Effect of Triton and Freezing on SDH Activity

Treatment	Activity nMoles-min^{-1}-mg^{-1}	Activity Recovered %
Untreated	6.19 ± .58	100
Triton X-100	3.40 ± .10	60
(Freeze/Thaw) & Triton X-100	3.45 ± .10	59
Triton X-100, Super	6.23 ± 1.2	55
(Freeze/Thaw) & Triton X-100, Super	6.12 ± .38	59
Triton X-100, Pellet	0.17 ± .08	2
(Freeze/Thaw) & Triton X-100, Pellet	0.28 ± .04	1

[a]Untreated mitochondria were freshly prepared and used prior to storage. The freeze-thawed preparations were subjected to five cycles of immersion of untreated mitochondria (1.25 ml, in a 13 ml Pyrex tube) into an acetone/dry ice bath, followed by thawing in a 25°C water bath. Where indicated, Triton X-100 was added at 5 μl/mg protein. Incubation, centrifugation, protein determination and assay procedures were as described in the text and Table 1.

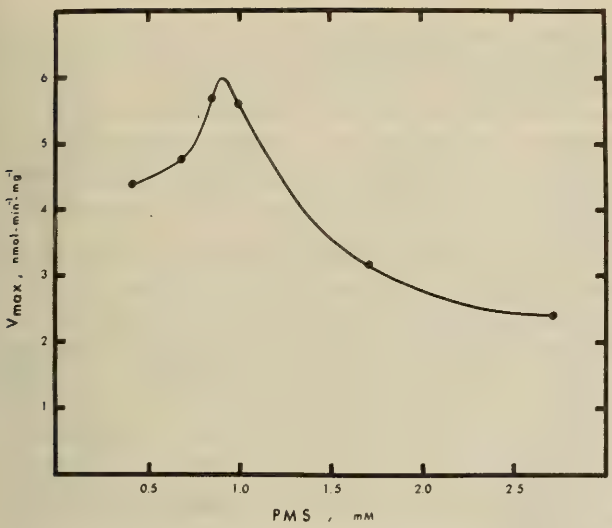

Fig. 1. Relationship between V^0_{max} and PMS Concentration. The procedures for obtaining the enzyme preparation, assay procedures, and statistical analysis are given in the text. For the determination of V^0_{max}, succinate concentrations ranged from 50–833 μM. Regression lines were obtained from either five or six concentrations of succinate, each concentration representing four or five assays in the presence of succinate and three assays in the absence of succinate. All lines were found to give $p \leq .05$, determined from their correlation coefficients and degrees of freedom.

sented here the notation V^0_{max} is used to emphasize that these values are derived at fixed concentrations of PMS and extrapolated to infinite succinate concentration. It is apparent that SDH activity is proportional to PMS at low concentrations but is inhibited at higher levels. The inhibition has been previously reported (14,15). The previously proposed mechanisms of inactivation, based on either a direct or indirect (21) oxidation of necessary sufhydryls, are believed insufficient to explain that observed in our study: (1) peroxides generated from reoxidation of PMS by molecular oxygen would be unlikely, due to the use of DCIP as a terminal electron-acceptor; (2) the results were based upon initial (15–45 seconds) activities before appreciable depletion of DCIP could occur, allowing for PMS/O_2 coupling. Under the conditions of our experiments the inhibition appears to asymptote towards a value which approximates a 50–60% reduction in activity from that obtained under optimal conditions of PMS concentration and substrate. This is the same general range of inhibition produced by a number of agents or treatments which have previously been considered to damage one of two sites of PMS reductase activity (16,17). Although the inhibitory effect on V^0_{max} has been recognized, and the appropriate procedures recommended to normalize data for comparison among laboratories, (14,15), no such precautions have been noted for the effect of PMS on K_m. In Figure 2, however, it is apparent that there is a significant effect upon the observed K_m for succinate. It also would appear that in the range where activity is proportional to the PMS concentration, the K_m changes little, within the limits of error for the experiment. However, at inhibitory concentrations of PMS the change in K_m becomes substantial, approximately an eightfold increase in K_m over a change in PMS concentration of 1.83 mM.

The Hill Equation (18) has been used to estimate the minimum number of binding sites for several enzymes, some more successfully than others (19,20). For the Hill analyses, V^0_{max} was estimated from the curve in Figure 1. The Hill Coefficient (n) is a measure of cooperativity between enzyme and ligand (in this case succinate or PMS). For succinate, the initial velocity was that

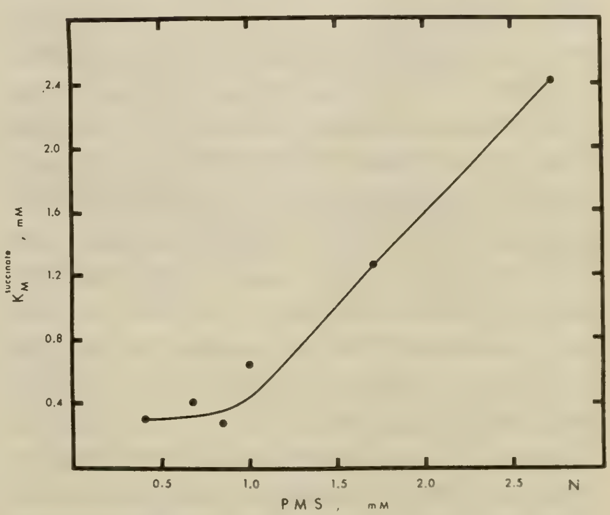

Fig. 2. Relationship of K_m succinate to PMS Concentration. All conditions and procedures involved in the derivations of K_m succinate are described in Figure 1.

Table 3[a].—Hill Coefficients

Binding of Succinate to SDH

PMS, mM:	2.67	1.67	1.00	0.83	0.67	0.50
n:	1.08	1.60	1.00	1.02	1.05	.968
p:	<.01	<.05	<.05	<.05	<.01	<.02

$\bar{n} = 1.12 \pm 0.047$

Binding of PMS to SDH
($PMS = 5.00 - 10.0 \times 10^{-4}M$)

succinate, mM:	.365	.260	.156	.104
n:	2.02	2.11	1.96	1.87
p:	<.02	<.05	<.05	<.05

$\bar{n} = 1.99 \pm 0.101$

Binding of PMS to SDH
($PMS = 8.33 - 26.7 \times 10^{-4}M$)

succinate, mM:	.417	.208	.104	.052
n:	2.54	3.00	2.91	2.98
p:	<.01	<.02	<.05	<.02

$\bar{n} = 2.86 \pm 0.215$

[a]Hill Plots were performed. For succinate, the plots were performed varying succinate, and at six different concentrations of PMS. For PMS, the plots were performed varying PMS over two ranges, (a) where activity is proportional to PMS and (b) where activity is inversely proportional to PMS. The Hill coefficient, n, for each condition, and the p-value (linearity of the plot) are given. The mean Hill coefficient, n, is given ± the standard deviation.

observed at constant PMS concentration and several concentrations of succinate, i.e., six different concentrations of PMS, but in each experiment the specified concentration of PMS was held constant while succinate was varied. For the n-value for PMS, a similar set of experiments was carried out except that the specified concentrations of succinate were held constant while PMS was varied. The reported value of n, is the mean of the n-values at each constant concentration of succinate or PMS derived from results obtained when the other was the variable. Table 3 summarizes the Hill Coefficient data. It is observed that the minimum effective number of binding sites for succinate was independent of PMS and yielded the value, $n = 1.12 \pm 0.043$. The minimum effective number of binding sites for PMS, however, was dependent upon its concentration and independent of succinate, and yielded $n = 1.99 \pm 0.101$ for the low, activation range of concentrations and $n = 2.86 \pm 0.215$ for the high, inhibitory range of PMS concentrations.

Discussion

Solubilization of SDH by Triton X-100 produces an active enzyme with reproducible characteristics. Disruption of the mitochondrial membrane by freeze-thawing does not affect the efficiency of the solubilization procedure and it would appear that 60% of unchanged enzyme is recovered. It would seem that upon treatment with this detergent the enzyme remains in a hydrophobic configuration (perhaps bound to other hydrophobic lipoproteins) that retains the same specific activity of the intact mitochondrial enzyme. In addition, it would appear that this procedure does not change the K_m for succinate as reported by Hatefi

and Stygall (21) nor the minimum number of binding sites for succinate when studied with the PMS-DCIP assay system.

However, as the data were analyzed, it appeared that PMS did, indeed, have an effect on SDH activity similar to that already reported (14), an increase in activity at low concentrations followed by inhibition in what might be considered as typical "substrate inhibition." From the Hill Coefficients it would appear that there is a degree of cooperativity in the binding between SDH and PMS. The degree of cooperativity changes as the concentration of PMS increases so that when calculated over the range where inhibition by PMS occurs, the Hill Coefficient, changes from 2 to 3. As inhibition increases, it appears to asymptote to a value about 60% of the maximum value. As noted earlier this was the degree of inhibition seen when one of the two PMS reductase sites had been altered. It is also apparent that over the range of inhibitory concentrations, PMS causes a very marked increase in the K_m for succinate. Thus, at the lower concentrations of PMS there is a degree of cooperativity which causes an increase in the activity of SDH to a maximum at about 0.9 mM. Above this concentration inhibition seems to result from a change in the enzyme-substrate binding characterized by an increase in the K_m for succinate and an increase in what appears to be the minimum number of binding sites for PMS. The additional binding of PMS brings about what may be considered as "substrate inhibition".

Thus, Triton X-100 solubilization of SDH yields an enzyme that has characteristic and reproducible kinetic characteristics in a simple and quick procedure.

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The Greenhouse Whitefly, Its Entrapment by Sticky Yellow Boards, and Tomato Yield in Suburban Yard-Gardens

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ABSTRACT

Sixty-four Better Boy® tomato plants were grown in 16 four-plant plots in yard-gardens in the Washington, D.C., area. Greenhouse whiteflies (*Trialeurodes vaporariorm*), which often infest outdoor tomatoes, were artificially introduced into all plots in June and July. A pair of sticky yellow, plastic boards was placed in each of eight plots in August and September. Board capture of whiteflies demonstrated their potential usefulness as monitoring devices of these insects outdoors.

There was no significant correlation between whitefly abundance and tomato yield in the high-vigor plants; however, these variables were negatively correlated in the low-vigor plants. Therefore, gardeners may be able to increase yield of less vigorous Better Boy® tomato plants by controlling their whiteflies.

In addition, this investigation revealed that whiteflies show marked variability in population build up on individual tomato plants; nontarget insects, pollen, dust, and other debris can greatly reduce the tackiness of the boards outdoors in only about 1 week; and the boards capture other pest insect species besides whiteflies, but they also capture beneficial insect species.

Introduction

Greenhouse whiteflies, *Trialeurodes vaporariorum* (Westwood), damage many cultivated plants including squashes, tomatoes, cucumbers, melons, lettuce, kidney beans, soybeans, strawberries, chrysanthemums, and poinsettias. These insects are significant pests in greenhouses (Lindquist et al., 1972) and outdoor gardens, harming plants by sucking their juices and depositing honeydew on them. The honeydew supports the growth of sooty mold fungus which interferes with plant photosynthesis and respiration, and fruit covered with this mold requires cleaning.

In greenhouses, whiteflies have been controlled mainly with chemical pesticides,

although alternative methods such as the chalcidoid wasp *Encarsia formosa* Gahan (Vet et al., 1980), fungi (Kanagaratnam et al., 1982), and sticky yellow boards (Webb and Smith, 1980) exist. The board's color attracts whiteflies and their adhesive coatings entrap them (Vaishampayan et al., 1975; Webb and Smith, 1980). Because greenhouse whiteflies can become abundant in vegetable gardens (pers. obs.) and some strains are resistant to many commonly used pesticides (Wardlow et al., 1975), we tested two experimental hypotheses concerning tomatoes grown in suburban yard-gardens: (1) sticky yellow boards can be used to reduce the population size of whiteflies within tomato plots and (2) tomato plants with light infestations of whiteflies produce more fruit than those with heavy infestations. These hypotheses as they relate to tomatoes grown indoors have been supported by experiments done in greenhouses (Lindquist et al., 1972; Webb and Smith, 1980), but they have not been tested outdoors.

Materials and Methods

Four Better Boy® tomato plants were planted in each of 16 0.9-by-1.2-m plots in 12 suburban-yard gardens in Bethesda and Glen Echo, Maryland in 1982. The plots were at least 7 m apart and were part of larger gardens or were isolated plots surrounded by lawn. The plants were placed at the corners of a 0.6-by-0.9-m rectangle centered within each plot. Each plant was supported by a 1.8-m wooden pole and its lateral shoots were removed throughout the growing season. Plants were treated with 5–10–5 fertilizer and occasional hornworms were eliminated by hand picking when found. The plots were tentatively designated as matched pairs (one plot with sticky boards and one without).

Three attempts were made to introduce whiteflies onto uninfested plants. On 16 June, 400 adults were released from vials into each plot. All 64 tomato plants appeared healthy at this time. On 22 June, 150 more whitefly adults were released from vials into each plot and between 22 June and the second week in July, a highly infested leaflet with whitefly pupae from an Early Girl® tomato plant was placed on any of the plants that remained uninfested.

Two plastic yellow boards were used to entrap whiteflies in each of eight tomato plots (Figure 1). The boards, manufactured by Almac Plastics of Maryland, Inc., were $0.3 \times 35 \times 35$ cm and sulfur yellow (rating 6A, Royal Horticultural Society, 1966). They were suspended by vertical cords attached to horizontal ones tied to the four poles in each plot. Board faces were parallel to one another and the top edges of the boards were at canopy height. Boards were placed in plots on 27 July, and coated with Tack Trap® thinned to a paintable consistency with Varsol®. On 11 August, entrapped whitefly adults were counted, the boards were cleaned, replaced, and repainted. On 16 September, the boards were removed for the second and last time and their entrapped whiteflies were counted.

Relative population sizes were determined from counts of immatures and adults in these ways. The relative number of pupae (living pupae and pupal skins) and eggs on a plant were ascertained by counting them on a 18-mm-diameter leaf disk using a dissecting microscope at from 7 to $30 \times$ magnification. Both pupae and eggs were counted in the third week of September. Pupae were counted on one leaf disk per plant that was taken from the penultimate leaflet of a leaf that was located about two thirds up a plant. Egg counts made in August are based on one disk per plant that was taken from a terminal leaflet, and those made in September are averages based on three disks per plant taken from terminal leaflets. The relative number of adults per plant was approximated to the nearest ten by counting the number of the top five leaves in the third week of July. We made counts of adults on every board on 11 August and 16 September by placing a 30-×-30-cm wire grid with 144 equally sized squares over each side and the whiteflies within the same 12 randomly chosen squares were counted and summed.

The "yield" of a tomato plant is desig-

nated as the total weight of its berries, based on all ripe or nearly ripe fruit over 30 g that it produced during its growth season. A "high-yield plant" is one of the 32 plants that produced from 2,129 to 8,219 g of fruit: a "low-yield plant," 520 to 2,119 g of fruit. A "heavily infested plant" is one of the 32 plants that had an August pupa-plus-egg count of greater than 20; a "lightly infested plant," a count of less than or equal to 20. Quantitiative analyses were made using SAS computer packages (Ray, 1982a, b). The Spearman correlation coefficient (SCC) was used to examine possible correlations between variables. t test analyses were adjusted for heteroscedasticity when necessary.

Results and Discussion

The tomato plants had 40.23 ± 5.03 SE (0–308, 64) whitefly eggs in August, 58.52 ± 11.23 (0–355, 62) eggs in September, 15.3 ± 22.28 (0–62, 64) pupae in August, and 123.36 ± 178.20 (10–1000, 64) adults in July. The 32 low-yield plants had 1459.8 ± 81.14 (520–2119) and the 32 high-yield plants had 4235.8 ± 291.95 (2129–8219) g of fruit. Yield for all 64 plants was 2847.8 ± 230.59 (520–8219) g of fruit.

The eight pairs of boards captured 730.8 ± 205.29 (200–1972) whiteflies per plot in September. However, our attempt to test the hypothesis that sticky yellow boards reduce the population size of whiteflies within tomato plots failed because tomato plants in matched plots showed marked between and within plot variability in size and whitefly infestation level as the growing season progressed. Likely reasons for this variability include genotypic and phenotypic differences among plants and microhabitat differences.

We tested the hypothesis that tomato plants with light infestations of whiteflies produce more fruit than those with heavy infestations by determining whether or not there was a negative correlation between whitefly number and tomato yield. To take plant vigor variability into account, we divided the 64 plants into the 32 more vigorous ones (high-yield plants) and the 32 less vigorous ones (low-yield plants). Whitefly (based on August pupa-plus-egg counts) and tomato yield were not correlated in the high-yield group, but they were negatively correlated in the low-yield one ($r = 0.007$, $p = 0.970$, $r = -0.372$, $p = 0.036$, respectively). Coupled with the fact that whiteflies reduce tomato yield indoors (Lindquist et al., 1972), this negative correlation suggests that these insects decrease yield outdoors of less vigorous tomato plants. Thus, gardeners may be able to increase production of less vigorous Better Boy® plants by controlling their whiteflies.

Further data analysis revealed eight other points about Better Boy® tomatoes, whiteflies, and sticky yellow boards under yard-garden conditions. First, the high-yield plants had 74.9 ± 17.97 (0–364) and low-yield ones had 36.1 ± 9.86 (0–260) pupae and eggs, showing a significant difference between groups ($p = 0.0013$, t test). Mean pupa-plus-egg count approached being correlated with mean yield ($r = 0.475$, $p = 0.063$). These findings suggest that microhabitats favoring vigorous tomato plants also favor whitefly population increase; that whiteflies may establish and develop better on healthy, vigorous tomato plants than on less vigorous ones; or both. The second suggestion contradicts the popularly held belief of some organic gardeners that healthy plants tend to ward off arthropod pests.

Second, although the tomatoes were all of the same horticultural strain, there was a marked difference in the ability of whiteflies to build up on individual plants within high- and low-yield groups. This may have been due to factors such as differences in biochemical and other phenotypic traits (as in poinsettias Biderbeck et. al., 1977). Tomato breeders should consider such factors in relation to developing whitefly resistant and repellant tomato strains.

Third, the same plants usually had high whitefly numbers in both July and August. The July adult count was positively correlated with the August egg count and pupa count ($r = 0.646$, $p = 0.0001$; $r = 0.508$, $p = 0.0001$; $N = 64$ plants; respectively).

Fig. 1. A plot of four tomato plants with two sticky yellow boards in place.

Thus, whiteflies tend to grow well on some plants, but not others, throughout this part of their growth season.

Fourth, the yellow boards should be useful in monitoring whitefly populations on tomatoes grown outdoors. In the eight plots, the number of whiteflies captured was positively correlated with the number of highly infested plants per plot in both August and September ($r = 0.824$, $p = 0.012$; $r = 0.776$, $p = 0.024$; respectively). The August per-plot count of adult whiteflies on boards was positively correlated with their July count on plants ($r = 0.910$, $p = 0.0001$) and the August and September per-plot counts of adults on boards were positively correlated ($r = 0.853$, $p = 0.001$).

Fifth, unfortunately, the kind of sticky yellow boards that we used, remained tacky for only about 1 week compared to about 3 months under greenhouse conditions (Webb and Smith, 1980). Outdoors, our boards lost stickiness because many kinds of insects besides whiteflies, pollen, dust, and other debris became mired in the Tack Trap®. In another outdoor study, Dapsis and Ferro (1983), who used yellow stakes coated with Tangletrap® to capture cabbage maggots, found that their traps also lost tackiness due to entrapment of

nontarget objects such as windblown soil particles.

Sixth, the boards captured other pestiferous insects besides whiteflies, such as squash vine borers and spotted cucumber beetles. However, they also trapped many beneficial insects including small bees, syrphid flies, ladybird beetles, lacewings, and parasitic wasps.

Seventh, although whiteflies evidently significantly decreased tomato yield on only low-yield Better Boy® plants; it may be worthwhile for gardeners to try to control these insects on both high- and low-yield plants because their honeydew supports the growth of sooty mold on fruits. This increases the labor necessary to clean them. Moreover, these insects build up on tomato plants and then move to squash, whose yields they evidently decrease outdoors (pers. obs.), and they move to cut flowers and house plants before they are brought indoors in autumn. Indoors, whiteflies can become abundant and markedly damage ornamental plants including *Fuchsia* and *Lantana* (pers. obs.).

Finally, a survey conducted by the Environmental Protection Agency in Dallas, Philadelphia, and Lansing, Michigan showed that homeowners used more potentially harmful pesticides per acre than farmers did in the surrounding agricultural land (von Rümker et al., 1972). Given the surprisingly high usage of pesticides in such urban and suburban areas and the abundance of yard-gardens, it should be worthwhile to develop integrated pest management (IPM) programs for such gardens. Sticky yellow boards would be useful as monitoring devices for whiteflies, and other pests. Further, an improved method of using sticky yellow boards could prove beneficial as an alternative to chemical pesticides utilized for whitefly control.

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Palladium Zeolites as Acetylene Hydrogenation Catalysts*

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ABSTRACT

Acetylene impurities in commercial ethylene streams are removed by selective hydrogenation over palladium/Al_2O_3 catalysts. This process produces economically undesirable side products such as ethane and oligomers. Mixtures of 0.3% C_2H_2, 0.4% H_2 and 99.3% C_2H_4 were prepared and palladium exchanged zeolites were tested for their catalytic activity as well as their ability to selectively hydrogenate acetylene to ethylene and to suppress oligomer formation. The zeolites were exchanged with sufficient $Pd(NH_3)_4Cl_2$ to produce 0.04 wt% palladium using conventional ion exchange procedures. At steady state conditions, Pd/Linde 13X was found to be not active; Pd/NaMordenite (back exchanged with Na_2CO_3), Pd/ZSM-5 and Pd/Silicalite were both active and selective for the acetylene hydrogenation system. The results show that palladium zeolites are potentially good selective hydrogenation catalysts. The reasons for this improved selectivity are discussed in terms of shape selectivity, Si/Al ratios, and acidity.

Introduction

In order to utilize ethylene for polymer manufacture, small quantities of acetylene impurity must first be removed since acetylene destroys the polymerization catalyst. Therefore, hydrogenation of trace acetylene in ethylene is an important industrial process. The necessary reduction of the acetylene concentration below 5 ppm[1] can be accomplished in two ways: physical separation of the acetylene from the ethylene, or selective hydrogenation of the acetylene preferably to the more desirable ethylene. Industrially, it is not economically feasible to separate the acetylene physically from the ethylene; hence, selective hydrogenation is employed.

This reaction system has been the subject of numerous in-depth studies.[2,3] Palladium supported on α-Al_2O_3 (alpha-alumina) was found to be the most selective catalyst for acetylene hydrogenation.[4–7]

Hydrogenation of acetylene produces economically undesirable side products such as ethane and oligomers (higher molecular weight hydrocarbons). Buildup of these oligomers on the catalyst surface reduces the catalyst's selectivity.[8] Thus, it seems that a catalyst which can discriminately prevent or suppress the formation of oligomers would be very desirable. With this in mind, zeolites, known for their shape selectivity, were loaded with palladium and tested for their ability to hydrogenate acetylene selectively and suppress oligomer formation. Suppression of oligomer formation would be due to steric hindrance resulting from the known shape-selective ability of zeolites.

Zeolites, commonly referred to as molecular sieves, are synthesized or formed in

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nature as crystalline, hydrated aluminosilicates. Structurally, they comprise a framework based on a three-dimensional network of

$$\begin{array}{c} O \\ | \\ O\text{—}Si\text{—}O \\ | \\ O \end{array}$$

and

$$\left[\begin{array}{c} O \\ | \\ O\text{—}Al\text{—}O \\ | \\ O \end{array}\right]^{-1}$$

tetrahedra linked together through common oxygen atoms. The SiO_4 group of the zeolite is electrically neutral whereas the AlO_4^- group has a net negative charge which is compensated by cations of Group I and II elements. Cations are located in the pores of the zeolite to balance the charge, thereby forming a neutral structure. Zeolites can be represented by the formula: $M_{2/n}O \cdot Al_2O_3 \cdot xSiO_2 \cdot yH_2O$ where M is the compensating cation with valency n.

The fundamental building blocks of all zeolites are silica (SiO_4) and alumina (AlO_4^-) tetrahedra. These tetrahedra are arranged so that each of the four oxygen atoms is shared in turn with another silica or alumina tetrahedron. Crystalline structures result that have cavities and channels connected by uniform pores of molecular dimension. Molecular sieves possess a large intracrystalline volume, a regular pore structure, and exchangeable cations. The chemical compositions and structural properties of the molecular sieves used in this investigation are listed in Table 1.

The small uniform pores and large intracrystalline volume characteristic of zeolites make them ideally suited as shape-selective catalysts or catalyst supports.[13] Since the first demonstration of molecular shape-selective catalysis by Weisz and Frillette in 1960,[9] numerous catalytic studies have been performed. In fact, studies with a molecular sieve as the catalyst support have been made on selective hydrogenation reactions using zeolites. Weisz *et al.*[9] have selectively hydrogenated 1-butene in a mixture of 1-butene and 2-methyl propene using platinum supported on a CaA zeolite and have shown that such shape selectivity is not observed for the same reaction with Pt on Al_2O_3. In a related paper, Weisz *et al.*[10] showed that a variety of different olefins could be selectively hydrogenated with Pt on CaA zeolite. Similarly, Dessau[11] has shown that ZSM-5 with Pt can selectively hydrogenate 1-hexene in a mixture containing the linear olefin with some branched olefins.

Molecular sieve effects with zeolite catalysts are not limited to hydrogenation reactions but occur whenever the zeolite pore size restricts the passage of the reactant(s) or the product(s) or the formation of a particular transition state inside the zeolite (Figure 1). Oftentimes, zeolites are not themselves catalytically active but are used to support metals and organic complexes which are the catalytically active centers for a particular reaction. In this study, palladium is the catalytically active center and zeolites are used as the catalyst support.

Since the prevention of oligomer formation in the acetylene hydrogenation reaction has not been successful to date with the industrial alumina (α-Al_2O_3) catalyst, and

Table 1.—Physical Data for Zeolites Studied[12]

Zeolite	Formula	Si/Al Ratio	Pore Size(Å)
Linde 13X	$Na_{58}Al_{58}Si_{134}O_{384} \cdot 240H_2O$	2.3:1	7.4
CaA	$Ca_6Al_{12}Si_{12}O_{48} \cdot 27H_2O$	1:1	5.0
HMordenite	$H_8Al_8Si_{40}O_{96} \cdot 24H_2O$	5:1	6.7 × 7.0
NaMordenite	$Na_8Al_8Si_{40}O_{96} \cdot 24H_2O$	5:1	6.7 × 7.0
ZSM-5	$Na_{1.35}Al_{1.35}Si_{94.65}O_{192} \cdot 16H_2O$	70:1	5.75 × 5.15
Silicalite	SiO_2	∞	5.75 × 5.15

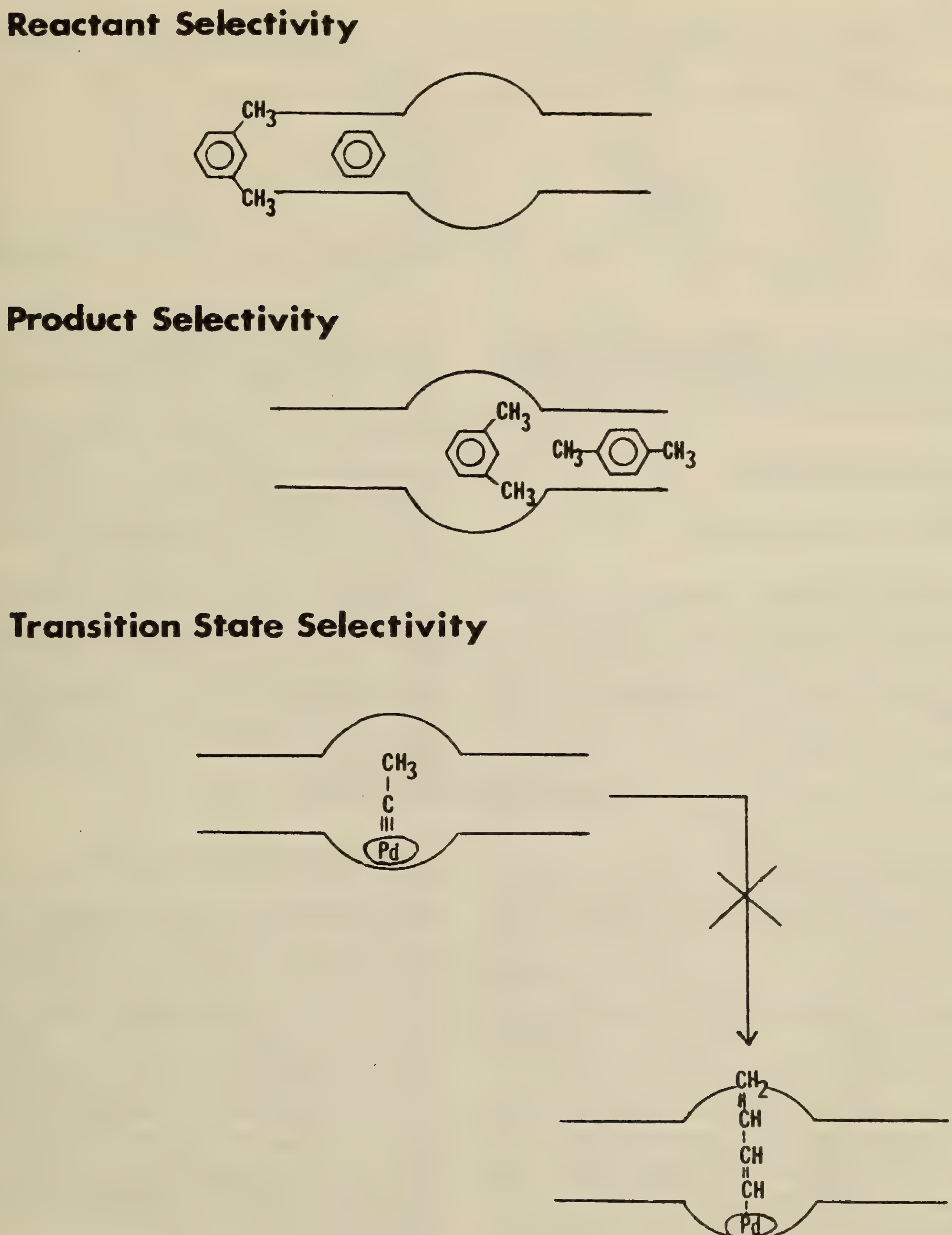

Fig. 1. Molecular Sieve Effect in Zeolites.

since it is believed that oligomers are formed by the addition of acetylene to an adsorbed precursor,[14] zeolites are used in this study as supports in the hope that they will suppress the unwanted oligomers to a level which is at least comparable to the present industrial catalyst.

It is possible that the limited space inside the zeolite will inhibit the chain growth phenomena leading to oligomers, particularly if the palladium atom is so located as to orient an adsorbed species preferably across the channel. If this is true, then the formation of molecules whose length exceeds the diameter of the zeolite channel may be inhibited. Table 2 gives the pore dimensions of the zeolites used and the lengths of some various hydrocarbons.

Table 2.—Molecule Size Versus Zeolite Pore Size[15]

Molecule	Size* (Å)	Zeolite	Pore Size(Å)
C_2H_2	3.3	Linde 13X	7.4
C_2H_4	3.9	CaA	5.0
n-C_4H_{10}	4.3	NaMordenite	6.7 × 7.0
1-Butene	4.5	ZSM-5	5.75 × 5.15
n-C_6H_{14}	6.7	Silicalite	5.75 × 5.15

*Length of Molecule

Note that a hydrocarbon such as n-hexane may not be formed easily inside of ZSM-5, for example, simply due to size limitations.

Experimental Procedure

A. Catalyst Preparation

Palladium catalysts were prepared by a conventional ion exchange[16] of the zeolitic support with an aqueous solution of a palladium salt followed by oxidation with air at 210°C for six hours and reduction to the metallic state with hydrogen at 350°C for fourteen hours. All zeolitic materials used as carriers for Pd, with the exception of CaA, were of the sodium form.

The palladium cations were introduced as follows: a very dilute solution of $Pd(NH_3)_4Cl_2$ was added dropwise at 25°C to the rapidly stirred aqueous slurry of the zeolite over a period of two hours. Stirring was continued for two hours after the addition of the salt solution was complete.

The quantity of palladium salt employed was calculated to yield the desired concentration of palladium (0.04 wt% Pd) in the finished catalyst. For the low Pd concentrations in this investigation, exchange of $Pd(NH_3)_4^{+2}$ ions with zeolite cations is expected to be 100% complete.[16,19] The final palladium content (0.04 wt%) is inferred from the experimental procedure; direct analysis to determine the actual palladium deposition is presently underway to quantitatively establish the Pd content.

The palladium cation-exchanged zeolite was filtered, washed free of chloride, and dried at 120°C. In most cases, a sodium sulfide test was performed on the filtrate to determine qualitatively the degree of cation exchange. No PdS precipitate was observed. In addition, all catalyst supports were tested without palladium and found to be completely inactive for acetylene hydrogenation. Although many of the catalysts with palladium rapidly deactivated with time, they were found to be at least initially active for hydrogenation.

The following nominally 0.04 wt% palladium catalysts were prepared: Linde 13X, CaA, NaMordenite, NaMordenite (back exchanged with Na_2CO_3),* ZSM-5, and Silicalite. An industrial catalyst, 0.04 wt% palladium on α-Al_2O_3, was obtained from ICI (ICI 38-1).

B. Apparatus and Procedure

The studies were carried out in a continuous flow stainless steel recycle reactor, shown in Figure 2. The recycle rate through the reactor was measured at 1 liter/minute and the fresh gas flow rates used were 13–15 ml/min; therefore, good back-mixing was assumed. In all runs, approximately 1.5 grams of catalyst was placed in the reactor between plugs of glass wool. The reactor was 3/8″ in diameter (ID) and 5″ in length.

In order to approximate the industrial situation, specially prepared gas supply tanks containing 99.3% ethylene, 0.3% acetylene, and 0.4% hydrogen were used in the experiments. The reactions were at room temperature (~25°C), 80°C, and 160°C and at ambient pressure.

* After the oxidation, reduction, and ion exchange processes, NaMordenite was slurried with a 1 M Na_2CO_3 solution for 2 hours. It was then reduced with H_2 at 350° for 2 hours.

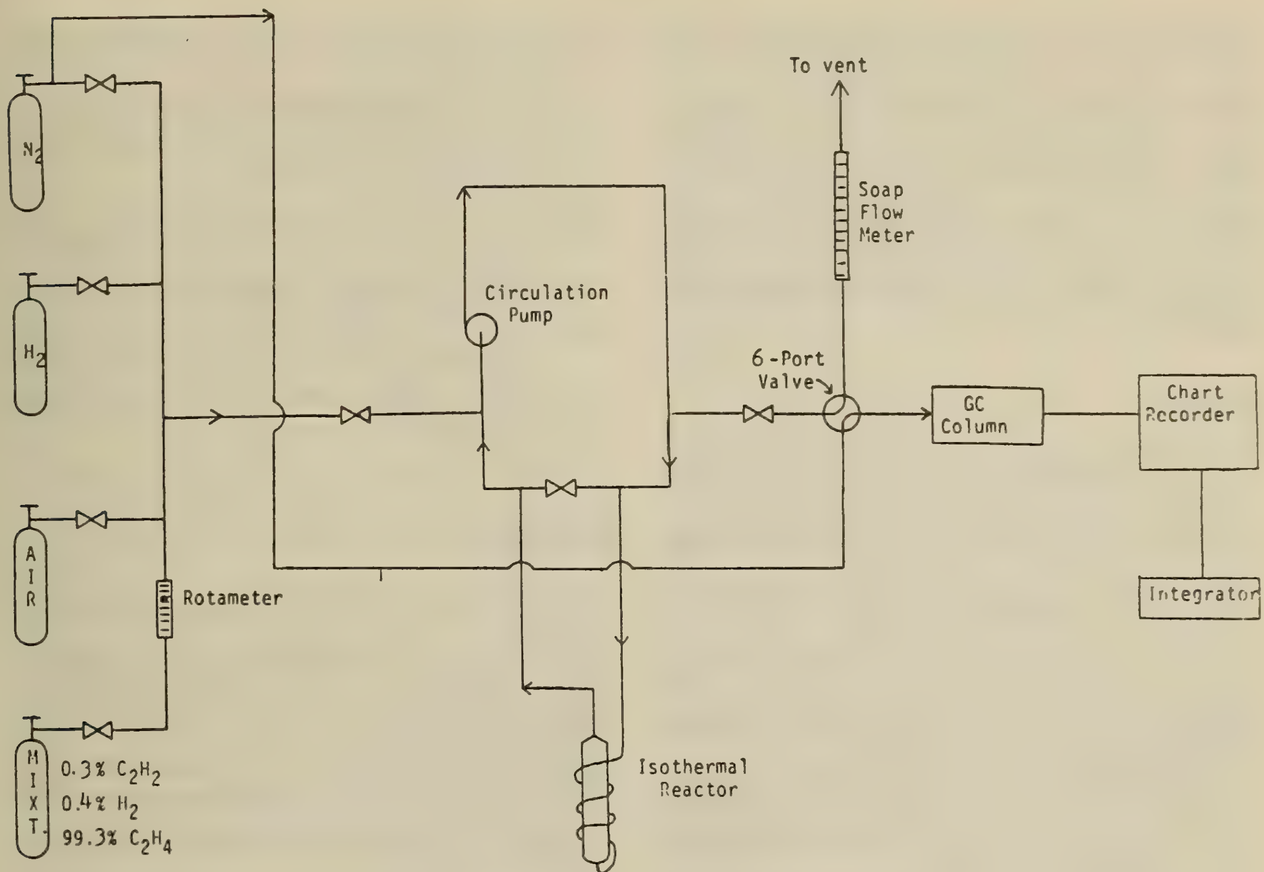

Fig. 2. Back Mixed Reactor For Zeolite Studies.

Analysis of both the feed mixture and reaction products was by gas chromatography. A Perkin-Elmer FID gas chromatograph Model 880 with a 10′ × 1/8″ (OD) stainless steel column filled with 80–100 mesh Porasil B packing was used for the separation of the C_2 hydrocarbons. The separation of higher molecular weight hydrocarbons (oligomers) was achieved by back-flushing the column after the C_2 compounds had eluted. The FID output was recorded on a Sargent Welch chart recorder and integrated by a Perkin-Elmer M-2 integrator.

After a catalyst was oxidized and reduced *in situ,* the reactant mixture was charged into the system. Periodically, product samples were sent to the gas chromatograph using a 6-port valve and N_2 gas as an inert carrier. The resulting chromatogram was used to calculate the conversion level of C_2H_2 and the selectivity to products such as C_2H_6, C_2H_4, and oligomers. Concentrations of reactants and products as well as moles of reactants and products were obtained by the relative areas on the chromatograms and an overall mass balance.

Conversion of C_2H_2 was defined as follows:

$$C_{C_2H_2} = \frac{\text{inlet } C_2H_2 \text{ conc.-outlet } C_2H_2 \text{ conc.}}{\text{inlet } C_2H_2 \text{ conc.}}$$

Selectivities for the system were defined as:

$$S_{C_2H_6} = \frac{C_2H_6 \text{ conc. in product}}{\text{inlet } C_2H_2 \text{ conc.-outlet } C_2H_2 \text{ conc.}}$$

$$S_{\text{oligomers}} = \frac{\text{oligomer conc. in product} \times 2}{\text{inlet } C_2H_2 \text{ conc.-outlet } C_2H_2 \text{ conc.}}$$

$$S_{C_2H_4} = 100 - S_{C_2H_6} - S_{\text{oligomers}}$$

The selectivity values obtained for C_2H_4 can be negative since ethane can be formed from ethylene as well as from acetylene. This can result in a net consumption of ethylene and, hence, a negative selectivity to ethylene if more ethylene is consumed through the production of ethane than is formed from the hydrogenation of acetylene.

Results

Table 3 summarizes the operating conditions as well as the conversion and selectivity values for the zeolite catalysts examined compared to the industrial catalyst at steady state conditions. Steady state was assumed to have occurred when no appreciable change with time in conversion and selectivity was noted. The results indicate that for acetylene hydrogenation:

1) the Linde 13X, CaA, and NaMordenite zeolites (without palladium) yielded no activity;
2) the Pd/Linde 13X catalyst yielded no activity;
3) the Pd/CaA and Pd/NaMordenite catalysts were active (40% and 85% conversion, respectively) but not selective to ethylene (−10% and −15% selectivity, respectively);
4) the Pd/NaMordenite (back exchanged with Na_2CO_3), Pd/ZSM-5, and Pd/Silicalite catalysts were all active (90%, 30%, and 75% conversion, respectively) and selective to ethylene (30%, 60%, and 50% selectivity, respectively).

Discussion

The Linde 13X, CaA, and NaMordenite zeolite (without palladium) were found to be unreactive for acetylene hydrogenation. This was as expected since acetylene hydrogenation is known to be a metal-catalyzed reaction; that is, a reaction which will not occur unless a metal catalyst like palladium is present.

The palladium zeolite which appears neither active nor selective for the hy-

Table 3—Conversion and Selectivity* Values Obtained in Selective Hydrogenation Reaction at Steady State.

Catalyst	Fresh Feed Rate ($ml \cdot g^{-1} \cdot min^{-1}$)	Temp. (°C)	$S_{C_2H_4}$ (%)	$S_{C_2H_6}$ (%)	$S_{oligomers}$ (%)	Conv. (%)
Linde 13X	9.9	22	*	*	no oligomers	~ 0
	9.9	80	*	*	no oligomers	~ 0
CaA	9.1	24	*	*	no oligomers	~ 0
	9.1	80	*	*	no oligomers	~ 0
NaMordenite	9.5	23	*	*	no oligomers	~ 0
	9.5	80	*	*	no oligomers	~ 0
HMordenite	9.8	25	*	*	oligomers	~ 0
	9.8	80	*	*	oligomers	~ 0
Pd/Linde 13X	9.3	22	*	*	no oligomers	~ 0
	9.3	80	*	*	oligomers	~ 0
Pd/CaA	9.4	23	*	*	no oligomers	~ 0
	9.4	80	−10	90	20	40
Pd/NaMordenite	10.2	24	−10	85	25	28
	10.2	80	−15	90	25	85
Pd/NaMordenite (back exchanged)	9.7	80	30	50	20	90
Pd/ZSM-5	9.7	80	55	40	< 5	10
	9.7	160	60	30	<10	30
Pd/Silicalite	9.3	80	50	40	<10	75
Pd/α-Al_2O_3	23.4	80	45	35	20	60

*When the conversion level is very low, the selectivity values become inaccurate and, subsequently, selectivity values for some of the catalysts have been omitted.

drogenation of acetylene at either 22°C or 80°C is Pd/Linde 13X. This is possibly due to formation and retention of oligomers in the pores resulting in blockage. This particular phenomenon of oligomer retention may be attributable to zeolites like Linde 13X which have a cage-like structure which has a larger diameter than its access ports. Other investigators[20] have observed oligomer blockage in a zeolite catalyst.

From Table 3 it would appear that oligomers are only formed in the Pd/Linde 13X catalyst at the higher temperature (80°C); however, it is believed that the oligomers were formed at both temperatures and only at the higher temperature did the oligomers have enough thermal energy to desorb and diffuse out of the pores.

The palladium zeolites which are active catalysts for acetylene hydrogenation but are not selective to ethylene are Pd/CaA at 80°C and Pd/NaMordenite at both 24°C and 80°C. A good conversion level (85%) is obtained for Pd/NaMordenite at 80°C, and a fair conversion level is obtained for Pd/CaA at 80°C (40%) and NaMordenite at 24°C (28%), but the selectivities of these catalysts to the various products are poor (Table 3). Certainly, the selectivities to oligomers for these catalysts are comparable to that of the industrial catalyst (20–25%), but the poor selectivities to ethane and ethylene would not make these commercially useful catalysts.

The palladium zeolites which are both active and selective for hydrogenation are Pd/NaMordenite (back exchanged with Na_2CO_3 at 80°C), Pd/ZSM-5 at 80°C and 160°C, and Pd/Silicalite at 80°C. Pd/NaMordenite back exchanged with sodium carbonate was prepared for the sole purpose of determining if acidity was a factor in oligomer formation. Decreasing the acidity of Pd/NaMordenite (through treatment with Na_2CO_3) considerably improved the catalyst's nature. The selectivity to oligomers was improved from 25% to 20%, the selectivity to ethane was improved from 90% to 50%, and the selectivity to ethylene was improved from −15% to 30%. Although the selectivity to oligomers observed with Pd/NaMordenite (back exchanged) was only slightly lower than the selectivity to oligomers observed with Pd/NaMordenite, it is, nonetheless, consistent with findings that oligomerization is decreased with decreasing acidity.[21,22] Direct comparison of Pd/NaMordenite (back exchanged) with the industrial catalyst is difficult because of the different conversion levels.

At low conversion levels (10% and 30%), Pd/ZSM-5 appears to be a highly selective catalyst. Bond *et al.*[23] have shown that a decrease in selectivity to ethane occurs with increasing temperatures. Here it is seen that the selectivity of Pd/ZSM-5 to C_2H_6 and C_2H_4 improves with increasing temperature.

Based on activity and selectivity values, Pd/Silicalite is the most promising zeolite catalyst tested thus far. At a temperature of 80°C, a conversion level of 75%, and a selectivity to oligomers less than 10%, Silicalite appears comparable to, if not better than, the industrial catalyst. The apparent improvement in the selectivity to oligomers observed with Silicalite over the industrial catalyst (10% and 20% selectivity to oligomers, respectively) may be the result of the shape-selective effect of the catalyst. If this is true, then shape-selective catalysis using zeolites is, indeed, promising for the selective hydrogenation of acetylene. Other factors beside shape-selectivity could be responsible for the suppression of oligomer formation. In particular, it is interesting to note that the catalysts which yielded the most promising results were those which had the highest Si/Al ratios (Table 1). Zeolites with high Si/Al ratios have fewer cations available for ion exchange and, consequently, the cations probably are much farther apart. Theoretically, this also means that no two palladium atoms will be near each other and oligomerization will be suppressed, since oligomerization is believed to required the joining of acetylene molecules adsorbed on adjacent palladium atoms.

Another factor which may account for the zeolite's selectivity is acidity. At temper-

atures of 25°C and 80°C a test with HMordenite (with no palladium) which has acidic hydrogen sites, promoted the formation of oligomers. It should be emphasized here that HMordenite was the only zeolitic support studied which showed any oligomerization activity at all. It is believed that the formation of oligomers in this zeolite is due to the acidic H-sites. The comparison of the Pd/NaMordenite catalyst with the Pd/NaMordenite back exchanged catalyst also indicates that acidity is a factor in oligomerization activity.

Conclusions

Zeolites are potentially good catalyst supports for palladium in the selective hydrogenation of acetylene. Determination of the reason behind their favorable performance is necessary if an even better catalyst is to be developed. It has been observed in this study that selectivity may be a function of the molecular sieve effect, the Si/Al ratios, and acidity in zeolites.

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Commentary

A Symposium Emphasizing Animal Behavior Held at Georgetown University, Fall, 1983

Edward M. Barrows

Department of Biology, Georgetown University, Washington, D.C.

Animal behavior, the scientific study of animal activities, strives to understand both the proximate (physiological) and ultimate (evolutionary) reasons why animals show their particular activities. It is a highly complex science that can be considered to include American Behaviorism, behavioral ecology, "behavioral evolution," behavior genetics, ethology (European Traditionalism), sociobiology, and humanology. It draws from concepts of all other sciences, especially ecology, evolution, and neurobiology. Further, animal behavior uses a diverse array of techniques including chemical, computer, mathematical, photographic, and statistical ones. Due to the wealth of behavioral information, much of it recently generated, it is unlikely that any one person could now fully understand the entire field.

The principal subdisciplines of animal behavior and their temporal occurrences are shown in Figure 1. All areas, except behavioral evolution, the investigation of animal behavior from an evolutionary perspective, essentially arose in the 20th century. Behavioral evolution, the oldest serious branch of behavior, germinated in the 19th century soon after the publication of Charles Robert Darwin's (1859) monumental book *On The Origin of Species by Means of Natural Selection or The Preservation of Favoured Races in The Struggle for Life.*

In celebration of the current burgeoning of animal behavior and the awarding of the 1973 Nobel Prize for Physiology or Medicine to Konrad Lorenz, Karl von Frisch, and Niko Tinbergen, for their studies of animal behavior, a symposium emphasizing animal behavior was held at Georgetown University in fall, 1983. One seminar was given during each of six successive weeks. In chronological order of presentation, the speakers and their seminar titles were:

Daniel J. Sullivan, S. J., Parasitic Microwasps of Aphids

Jeffrey R. Aldrich, What Makes a Bug Behave? Perfumes and Prophylactics

Richard M. Duffield, Behavioral and Chemical Studies on Bee and Wasp Exocrine Glands

George Middendorf III, Social Organization in Yarrow's Lizards

Luther P. Brown, Maintenance of Horn Size Variation and Its Consequences in

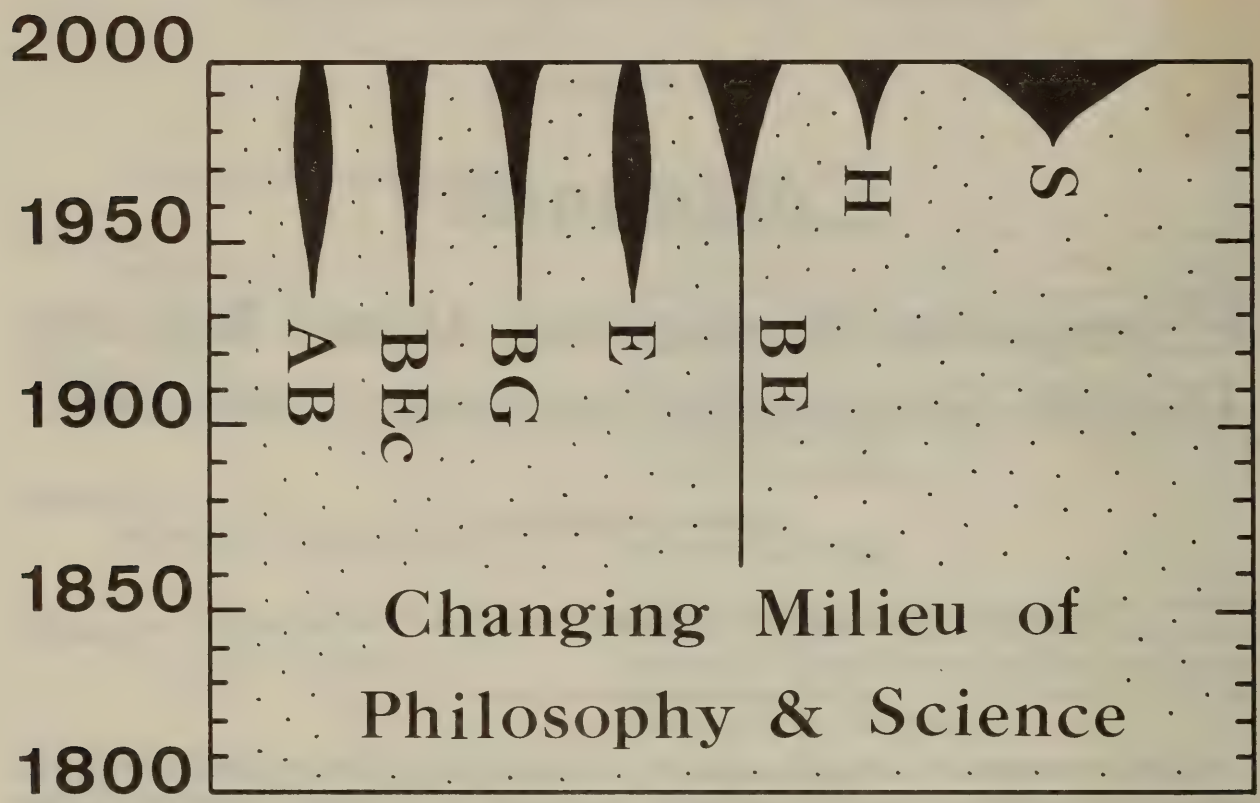

Fig. 1. Amounts of activity in subbranches of animal behavior. In any particular year, the width of a subdiscipline suggests the relative amount of activity that occurred or will occur in it, based on[1, 2, 3]. AB, American Behaviorism; BE, "behavioral evolution;" BEc, behavioral ecology; BG, behavior genetics; E, ethology; H, humanology; S, sociobiology.

Fungus Beetles *Bolitotherus cornutus* (Tenebrionidae)

Devra G. Kleiman, Behavioral Characteristics Associated with a Monogamous Mating System in the Golden Lion Tamarin, A New World Primate

Four of these speakers have contributed the following papers to this symposium series.

Acknowledgements

I thank Professors George B. Chapman and Peter K. Chen, both of the Department of Biology, Georgetown University, for encouraging this symposium, the speakers, and many others who helped it to come into fruition. Professors Irving Gray and Joseph H. Neale kindly extended an invitation from the Journal of the Washington Academy of Sciences to publish this series of papers.

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Interspecific Tertiary Parasitoidism between Two Aphid Hyperparasitoids: *Dendrocerus carpenteri* and *Alloxysta megourae* (Hymenoptera: Megaspilidae and Cynipidae)

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ABSTRACT

The behavior of aphid hyperparasitoids is briefly reviewed, including their taxonomy and ecological impact. Interspecific tertiary parasitoidism between the ectophagous megaspilid *Dendrocerus carpenteri* and the endophagous cynipid *Alloxysta megourae* was studied. The primary parasitoid was *Aphidius smithi*, using the pea aphid, *Acyrthosiphon pisum*, as the host. During 17 test days available for attack by the second hyperparasitoid, *D. carpenteri*, on the host inside the dead aphid "mummy," its overall success was 31.4%. Tertiary parasitoidism, however, was not possible during all 17 test days. Although test days 1–8 resulted in average *D. carpenteri* emergence of 49.3%, tertiary parasitoidism was not in fact occurring during this period because the first hyperparasitoid, *A. megourae*, was still inside the *A. smithi* larva within the mummy. Only during test days 9–17, could tertiary parasitoidism be accomplished when the larva of *A. megourae* was feeding externally on its primary host larva, and was thus available to be attacked by *D. carpenteri*. Yet, even then, only on test days 9 and 10 did *D. carpenteri* reach a peak emergence of 50.0%. Thereafter, the success rate of tertiary parasitoidism declined markedly, so that the average emergence of *D. carpenteri* during the remaining test days 11–17 was only 8.1%. Host specificity by *D. carpenteri* may account for this decline.

Introduction

Aphids are world-wide pests of agricultural crops, orchard and forest ecosystems. Fortunately, they are attacked by a number of natural enemies, especially by the two types of beneficial entomophagous insects: 1) *predators*, such as ladybird beetles (Coleoptera: Coccinellidae), and 2) *parasitoids*, such as the "parasitic" microwasps (Hymenoptera: Aphidiidae and Aphelinidae). These latter are the wasp parasitoids that serve as hosts for our present research. They are often called "parasites" in earlier

publications, but "parasitoid" is a more precise term which indicates that the host is killed by larval progeny, not by an adult female wasp that has oviposited into her aphid host.

Primary Parasitoids

The beneficial wasp used in our experiments was the aphidiid parasitoid, *Aphidius smithi* Sharma and Subba Rao. It has only one host in which its progeny can develop: the pea aphid, *Acyrthosiphon pisum* (Harris). The female wasp has a typical oviposition behavior: after initial contact has been made with a host aphid by antennal tapping, she stands facing the aphid and bends her abdomen anteriorly beneath the thorax and between the legs. Then, by moving her abdomen forward, she quickly inserts her ovipositor into the aphid and deposits an egg in the hemocoel. The egg hatches, and there are four larval instars during which time the aphid is gradually devoured internally. After approximately 8 days, a fourth instar larva spins a cocoon inside the dead aphid, and the latter's skin becomes hard and turns from green to light brown, being referred to as a "mummy." The prepupal, pupal and preadult stages develop within the mummy over the next 4 days. Approximately 12 days after the egg was originally deposited inside the aphid, the new adult cuts a circular emergence hole in the dorsum of the mummy and pulls itself out. This hole has an attached lid made of mummy skin.

Hyperparasitoids

As might be expected in such a plant-aphid-parasitoid complex, however, there is yet one higher trophic level, viz., that of the secondary parasitoids or hyperparasitoids. These Hymenoptera attack the beneficial primary parasitoids.[22, 24] Because of their interference with the impact of primaries on aphids, hyperparasitoids are considered detrimental to a biological control program, and are never purposely introduced into a region.[8, 10] There continues to be some debate, nonetheless, about the actual harm and even instead, the possible positive beneficial role of hyperparasitoids in maintaining a balance between populations of insect species in the ecosystem because multispecies complexity might help to effect community stability.[4, 9, 14, 16, 17, 18, 19, 21] Hence, aphid hyperparasitoids provide a microcosm for research on this fascinating and practical ecological puzzle.

Taxonomy

Hyperparasitism and its associated behaviors evolved in three superfamilies of Hymenoptera: Chalcidoidea, Ceraphronoidea, and Cynipoidea.[8] A currently acceptable summary of the five families and nine genera of these aphid hyperparasitoids is given below:

1) **Superfamily Chalcidoidea:**
   - a) Family Pteromalidae:
     Asaphes, Pachyneuron, Coruna
   - b) Family Encyrtidae:
     Aphidencyrtus
   - c) Family Eulophidae: *Tetrastichus*
2) **Superfamily Ceraphronoidea:**
   - a) Family Megaspilidae:
     Dendrocerus (=*Lygocerus*)
3) **Superfamily Cynipoidea:**
   - a) Family Cynipidae (Subfamily Alloxystinae):
     Alloxysta (=*Charips*),
     Phaenoglyphis, Lytoxysta

In order to examine possible relationships between taxonomy and behavior, it is useful to divide aphid hyperparasitoids into two major categories based on their larval feeding behavior: *endo*phagous and *ecto*phagous hyperparasitoids. In *endo*parasitoids, a female wasp deposits her egg inside a primary parasitoid larva while it is developing inside the live aphid before it is killed or "mummified," and then the hyperparasitic larva feeds internally on the primary larva. In *ecto*parasitoids, a female wasp deposits her egg on the surface of a primary parasitoid larva only after the aphid is killed and mummified, and then the hyper-

parasitic larva feeds externally on the primary larva, but still within the mummy. Therefore, in view of these two different behaviors of both the adult female wasp and her resulting hyperparasitoid larva, the taxonomic listing of genera given above can be rearranged to reflect their general behavior:

1) *Endo*parasitoids:
   Alloxysta (=*Charips*), *Phaenoglyphis, Lytoxysta,* and *Tetrastichus*;
2) *Ecto*parasitoids:
   Dendrocerus (=*Lygocerus*), *Asaphes, Pachyneuron,* and *Coruna*

Aphidencyrtus aphidivorus (Mayr) is a special case because it has a "dual" ovipositional behavior. Although it is in the category of being *endo*parasitic, it can attack the primary parasitoid larva either while the aphid is still alive as *A. megourae* does, or also after the mummy is formed in the manner of *D. carpenteri.* In both cases, however, the egg of the *A. aphidivorus* female is laid inside a primary parasitoid larva where it feeds as an endophagous hyperparasitoid. Hence, *A. aphidivorus* closely resembles the typical behavior of an endoparasitoid larva, yet the adult female can show both kinds of ovipositional behavior. Experiments have shown that when given a "choice" of hosts (primary larva either in a live aphid or in a mummy), the second of the dual attack behaviors is preferred, viz., oviposition into the primary parasitoid larva after mummy formation.[11]

Tertiary Parasitoidism

Besides attacking primary parasitoids, aphid hyperparasitoids can also attack each other, resulting in *tertiary* parasitoidism. This has been demonstrated, at least in the laboratory, in several combinations of cases:

1) *Intra*specific tertiary parasitoidism or *auto*hyperparasitoidism:
   a) When a second adult aphid hyperparasitoid, *Dendrocerus carpenteri* (Curtis), successfully attacked and oviposited on a first *D. carpenteri* larva developing inside a dead aphid mummy. The progeny of the second *D. carpenteri* female fed as a larva on the first *D. carpenteri* larva and eventually emerged as an adult 16 days later.[1]
   b) When a second *Asaphes lucens* (Provancher) does the same to a first *A. lucens* larva, and emerges as an adult 21 days later.[13]
2) *Inter*specific tertiary parasitoidism or *allo*hyperparasitoidism:
   a) When the adult aphid hyperparasitoid, *Asaphes californicus* Girault, successfully attacked and oviposited on another aphid hyperparasitoid, *Alloxysta victrix* (Westwood). The larva of the *A. californicus* fed on the *A. victrix* larva inside the mummy and eventually emerged as an adult 21 days later.[20]
   b) When *Dendrocerus carpenteri* (Curtis) does the same by attacking the larva of *Alloxysta megourae* (Ashmead). This last example of interspecific tertiary parasitoidism forms the basis of this paper, and a brief introduction to the methodology of our research is given below.

In our study, the primary endoparasitoid, *Aphidius smithi*, was allowed to parasitize the pea aphid, *Acyrthosiphon pisum,* in the laboratory. The *A. smithi* egg hatched in 2 days and, under our laboratory conditions, after 6 days it would have developed into a fourth instar larva. However, on that day, the endophagous hyperparasitoid, *Alloxysta megourae* (Ashmead), was permitted to oviposit within the developing *A. smithi* larva that was slowly devouring the still live pea aphid (Table 1). The *A. megourae* egg hatches 2 days later, or about the same time as the *A. smithi* larva kills the aphid, spins a cocoon inside the dead aphid, and the "mummy" is formed. This would ordinarily occur on the eighth day after the *A. smithi* egg was initially deposited inside the live aphid.

After hatching, the *A. megourae* feeds in-

Table 1.—Composite life cycles of a primary parasitoid, *Aphidius smithi*, and a first hyperparasitoid, *Alloxysta megourae*, in the pea aphid under experimental laboratory conditions when an aphid mummy is attacked by a second hyperparasitoid, *Dendrocerus carpenteri*, during the 17 test day period.

Age in days	*Aphidius smithi*	Age in days	*Alloxysta megourae*	17 Test days	
0	Egg deposited in aphid				
1					
2	1st larval instar				
3					
4	2nd larval instar				
5	3rd larval instar				
6	4th larval instar	0	Egg deposited in *A. smithi*		
7		1			
8	Host aphid mummified[a]	2	Egg hatches	1	
		3		2	
		4	1st larval instar	3	
		5		4	
		6	2nd larval instar	5	
		7		6	
		8	3rd larval instar	7	
		9		8	
		10	Mature larva feeds externally	9	*Dendrocerus carpenteri* has only 17 test days to attack the mummy[c]
		11		10	
		12	Prepupa (meconium voided)	11	
		13	Pupa	12	
		14		13	
		15		14	
		16	Preadult	15	
		17		16	
		18		17	
		19	Adult *A. megourae* emerges[b]		

[a] When hyperparasitized by *A. megourae,* the *A. smithi* larva ceases development.
[b] When hyperparasitized by *D. carpenteri,* the *A. megourae* will never emerge.
[c] If successful, an adult *D. carpenteri* emerges 16 days after its mother lays her egg.

ternally as an endoparasitoid on the *A. smithi* host causing the latter to cease further development inside the mummy. On the tenth day after the *A. megourae* egg was deposited, the larva emerges from the deteriorating *A. smithi* larva and feeds externally on its remains. The *A. megourae* completes its development while still inside the mummy, and becomes an adult on approximately the nineteenth day after oviposition. In emerging from the mummy, the adult cuts a distinctive jagged hole and will soon copulate if a mate is available.

The second hyperparasitoid is ectophagous, and so the *Dendrocerus carpenteri* (Curtis) female can attack her host only after the mummy is formed. In the sequence of events just described, the mummy is available for attack only during 17 days (Table 1). Our present research studied the results of permitting a *D. carpenteri* female to oviposit on the surface of whatever host was inside the mummy, i.e., either the *A. smithi* larva already parasitized by *A. megourae,* or the *A. megourae* larva itself. In both cases, an adult *D. carpenteri* would emerge approximately 16 days after its mother had oviposited. These experiments were conducted with replicates for each of the 17 available "test days."

Materials and Methods

The pea aphid, *Acyrthosiphon pisum,* served as the laboratory host in this study, and was reared on broad bean, *Vicia faba* Linnaeus. The primary parasitoid was *Aphidius smithi,* and there were two hyperparasitoids: the endoparasitic cynipid *Alloxysta megourae*, and the ectoparasitic megaspilid *Dendrocerus carpenteri.* All insects were laboratory reared in a controlled

bioclimatic chamber according to the method described in an earlier publication.[1] The daytime (16 hr) temperature was 21.1 ± 0.6°C at 75 ± 5% RH, while nighttime (8 hr) temperature was 15.5 ± 0.6°C at 85 ± 5% RH.

Parasitizing the fourth instar aphid by the primary parasitoid wasp was done in a glass cylinder or "stinging-tube" used by Matejko and Sullivan.[15] This reference on the bionomics and behavior of *Alloxysta megourae* also detailed how an *A. megourae* female attacked and oviposited into a parasitized aphid containing a 6-day-old *A. smithi* larva. In our procedure, about 15–20 parasitized aphids were placed in the glass stinging-tube with 3–4 mated *A. megourae* females. After 6 hr, the hyperparasitoids were removed and the live, parasitized (and now hyperparasitized) aphids were returned to broad bean plants. Here, each hyperparasitized aphid remained on a plant while feeding normally until it was killed by a primary larva developing within it. The dead aphid became completely mummified within 24 hr. As shown in Table 1, this occurs about 8 days after the initial oviposition by an *A. smithi* female.

After 2 days, these mummies were removed from the broad bean plants and were placed in uncoated Dixie® containers covered with clear plastic covers. Only those mummies with "wound scars," indicating hyperparasitoidism by *A. megourae,* were used in the next step of the experiment on tertiary parasitoidism.[20]

Each aphid mummy parasitized by *A. smithi* and hyperparasitized by *A. megourae* is normally attached to the broad bean leaf. We did not pry the mummies loose from this substrate, but instead carefully cut out the broad bean leaf tissue around each mummy with a pair of fine scissors. This leaf area was needed by a female *D. carpenteri* because she uses it as a substrate on which to anchor herself as she backs into the mummy when she oviposits.[1] This oviposition behavior is unlike the two species in the genus *Asaphes* that had been studied earlier, viz., *A. californicus* and *A. lucens.* In these cases, the female climbs atop a mummy and oviposits through its dorsum.[12, 20] One such mummy was placed in a 60 × 15 mm, covered plastic petri dish into which one mated female *D. carpenteri* was introduced for 1 hr and then removed. Since a *D. carpenteri* female must first drill a hole through the mummy with her ovipositor, we used the presence of such a "drill hole" as proof that a particular mummy had at least been attacked. Mummies without such drill holes were discarded. The remaining experimental mummies were held for a minimum of 25 days to allow time for the two different species of hyperparasitoids (*A. megourae* or *D. carpenteri*) to emerge even if development were delayed. In our experiments, approximately 25 replicates were done for each of the 17 test days, making a total of 420 mummies that were used.

Time of Attack

Our experiments on interspecific tertiary parasitoidism were based on the time sequence of development inside the mummy of the first hyperparasitoid as summarized above in the introduction and in Table 1. Because *D. carpenteri* attacks its host only after formation of a mummy by an *A. smithi* larva, our experiments on interspecific tertiary parasitoidism were limited to 17 "test days," i.e., from mummy formation (which coincides with hatching of an *A. megourae* egg) to the day before emergence of *A. megourae* as an adult from the mummy.

Results and Discussion

Success Rate of Tertiary Parasitoidism

Of the 420 mummies that had definitely contained both hyperparasitoids, 341 adult hyperparasitoids emerged. Non-emergence or mortality of the remaining 79 mummies will be discussed later. During the 17 test days available for attack by the second hyperparasitoid, *D. carpenteri,* its mean success rate was 31.4%. However, as in the three earlier reports on similar experiments

involving two hyperparasitoids, *Asaphes californicus* and *Alloxysta victrix,*[20] *Dendrocerus carpenteri* and *D. carpenteri,*[1] or *Asaphes lucens* and *A. lucens,*[13] a first hyperparasitoid is not always directly available for attack as a host. In our experiments, the vulnerability of *A. megourae* depends on its developmental stage and the time sequence of the 17 test days. Hence, regardless of which hyperparasitoid (first or second) eventually emerges as an adult, true tertiary parasitoidism may not have occurred. In this case, the endophagous *A. megourae* larva feeds within an *A. smithi* primary larva during the first 8 test days. *A. megourae* could not be attacked directly, therefore, because the ectophagous *D. carpenteri* larva is feeding on the surface of whatever host is inside a mummy at the time. During these first 8 test days, the only available host is an *A. smithi* larva within which is the first hyperparasitoid, *A. megourae* (Table 1). The second hyperparasitoid, *D. carpenteri,* continues to feed externally, and there is no possibility of direct tertiary parasitoidism on an *A. megourae* larva, although this first hyperparasitoid is indirectly consumed because at this time, it is still within the *A. smithi* larva.

Test days 1–8

Based on 152 adults that emerged from mummies of these first 8 test days, the average of the two hyperparasitoids was 50.7% *A. megourae* and 49.3% *D. carpenteri.*

Test days 9–10

Beginning with test day 9, as explained above, an *A. megourae* larva emerges from an *A. smithi* host inside the mummy and is exposed for the first time to direct attack by a *D. carpenteri* female (Table 1). Only now could true or direct tertiary parasitoidism occur, and it might be expected that at least beginning with these 2 days, the second hyperparasitoid, *D. carpenteri,* would be more successful. Yet, of the 40 adults that emerged from mummies of test days 9 and 10, the averages were equal: 50.0% *A. megourae* and 50.0% *D. carpenteri.*

Test days 11–17

The remaining test days 11–17 are grouped together because they represent a marked drop in the success of *D. carpenteri.* Of the 149 hyperparasitoids that emerged, only 8.1% were *D. carpenteri.* This failure at tertiary parasitoidism resulted in 91.9% of the emerged adults being *A. megourae.* In fact, no *D. carpenteri* emerged on the last 3 test days (15–17).

Evaluation

Although there is definitely some tertiary parasitoidism by *D. carpenteri* during test days 9–14 (when *A. megourae* becomes available for attack), the success rate is quite low. This is especially evident as the diminishing emergence of this second hyperparasitoid drops to zero during the last 3 test days when no *D. carpenteri* emerged, thus lowering the average for test days 11–17 to 8.1%. This was not entirely unexpected, however, because it had already been reported,[20] that in the latter days of development in similar experiments using 2 different hyperparasitoid species, *Alloxysta victrix* pupae and preadults become highly sclerotized. This deterred oviposition and tertiary parasitoidism by the second hyperparasitoid, *Asaphes californicus.* This also occurs between *A. megourae* and *D. carpenteri.*

Low success at tertiary parasitoidism was also reported intraspecifically between *Dendrocerus carpenteri* attacking another *D. carpenteri,* wherein the second hyperparasitoid had a success rate of only 8.0%.[1] It was suggested that a defensive behavior (violent twitching) and morphological changes (spine-like projections and a posterior conical process) in fourth instar larvae of *D. carpenteri* caused this relative failure at tertiary parasitoidism by the second *D. carpenteri.* Also, the venom of *D.*

carpenteri may have been less effective against its own species (intraspecific immunity) than against the more susceptible *Aphidius smithi* primary larva as shown in the color plate published by Bocchino and Sullivan in 1981.[2]

Host Specificity

Another explanation for this low success rate at tertiary parasitoidism by *D. carpenteri* may be a certain degree of "host specificity" that we did not suspect. Normally, we have no problem in rearing *D. carpenteri* on *A. smithi* in the laboratory when maintaining the colony. It is even the dominant hyperparasitoid (64.7%) in New Jersey alfalfa fields when *Aphidius ervi* Haliday mummies were collected over a 3-yr period and the hyperparasitoids permitted to emerge in the laboratory.

For many years, host specificity had been discounted among the hyperparasitoids, but evidence to the contrary has gradually been presented that this may not be true for the genus *Alloxysta*.[3, 5, 7, 21, 23] Perhaps *D. carpenteri* is another example of a hyperparasitoid displaying some degree of host specificity. It may be that a host other than a primary parasitoid larva such as *Aphidius* spp. is unsuitable either for oviposition or larval development. It should be remembered that feeding behavior with regard to number of species eaten is a continuum, and that it is only for convenience that at each end of this spectrum, the terms monophagy and polyphagy are used. With this in mind, van den Bosch had emphasized that "host specificity" should not have a restricted meaning, but can range from monophagy to some level of oligophagy.[23] He predicted that further study of hyperparasitoids would reveal a kind of flexible host specificity in other groups similar to that shown in the genus *Alloxysta* that is an endoparasitoid. Perhaps *Dendrocerus carpenteri*, as demonstrated in this present research, is one more example. This would be especially interesting because *D. carpenteri* is an ectoparasitoid, and therefore in a class usually considered more polyphagous.

Mortality

Of the 420 mummies used in these experiments, 79 or 18.8% showed no parasitoid emergence, neither *A. smithi, A. megourae* nor *D. carpenteri*. These mortality results are similar to the three other parallel experiments on tertiary parasitoidism conducted under similar laboratory conditions referred to earlier: *Alloxysta victrix* and *Asaphes californicus* (18.0%),[20] *Dendrocerus carpenteri* and *D. carpenteri* (15.0%),[1] *Asaphes lucens* and *A. lucens* (20.0%).[13]

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Semiochemicals from a predaceous stink bug, *Podisus maculiventris* (Hemiptera: Pentatomidae)[1]

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ABSTRACT

A total of 19 volatile compounds from 6 different exocrine glands have been identified for the spined soldier bug, *Podisus maculiventris.* In addition to the exocrine glands responsible for the well-known stench of stink bugs, there are other odor-producing glands in adults and immatures whose secretions are not released in defensive contexts. The secretion from the large dorsal abdominal glands of adult males is a blend of (E)-2-hexenal, benzyl alcohol, and monoterpenes and serves as a long-range attractant pheromone. At least 4 parasitic species use this pheromone as a kairomone to find the bugs. The secretions from the other exocrine glands found in the spined soldier bug are also idiosyncractic, suggesting they, too, are pheromones. Possible pheromonal roles for the various volatile secretions of *P. maculiventris* are discussed.

Insects are fantastic natural product chemists. For example, Blum[1] listed 620 different defensive compounds (allomones) from about 1000 arthropod species, the majority insects. Intraspecific chemical signals (pheromones), often consisting of blends of compounds, have been identified and synthesized for nearly 250 insect species.[2] The so-called true bugs (order Hemiptera, suborder Heteroptera) account for about a tenth of the known insect allomones, but none of the synthetic insect pheromones.[1, 2]

Descriptions of sexually dimorphic exocrine glands in predaceous stink bugs (Pentatomidae: Asopinae)[3] suggest that these hemipteran insects also use pheromones. Aldrich *et al.*[4] identified the components of a male-specific secretion from a common North American predaceous pentatomid, *Podisus maculiventris* (Say), the spined soldier bug. We have demonstrated that this secretion is, in fact, a long-range attractant pheromone and that insect parasites of *P. maculiventris* use the pheromone as a kairomone to locate this host.[5] The adult and immature stages of the spined soldier bug possess additional exocrine glands that produce the familiar stench of stink bugs,[6] plus other smaller exocrine glands of unknown function. Volatiles from six different exocrine glands have now been identified. In this paper, the positions and relative sizes of these glands are illustrated, the chemical compositions of the newly identified secretions are reported, and the compositions of previously examined secretions are updated by inclusion of recently identified compounds.

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Mention of a commercial product does not constitute an endorsement by the USDA.

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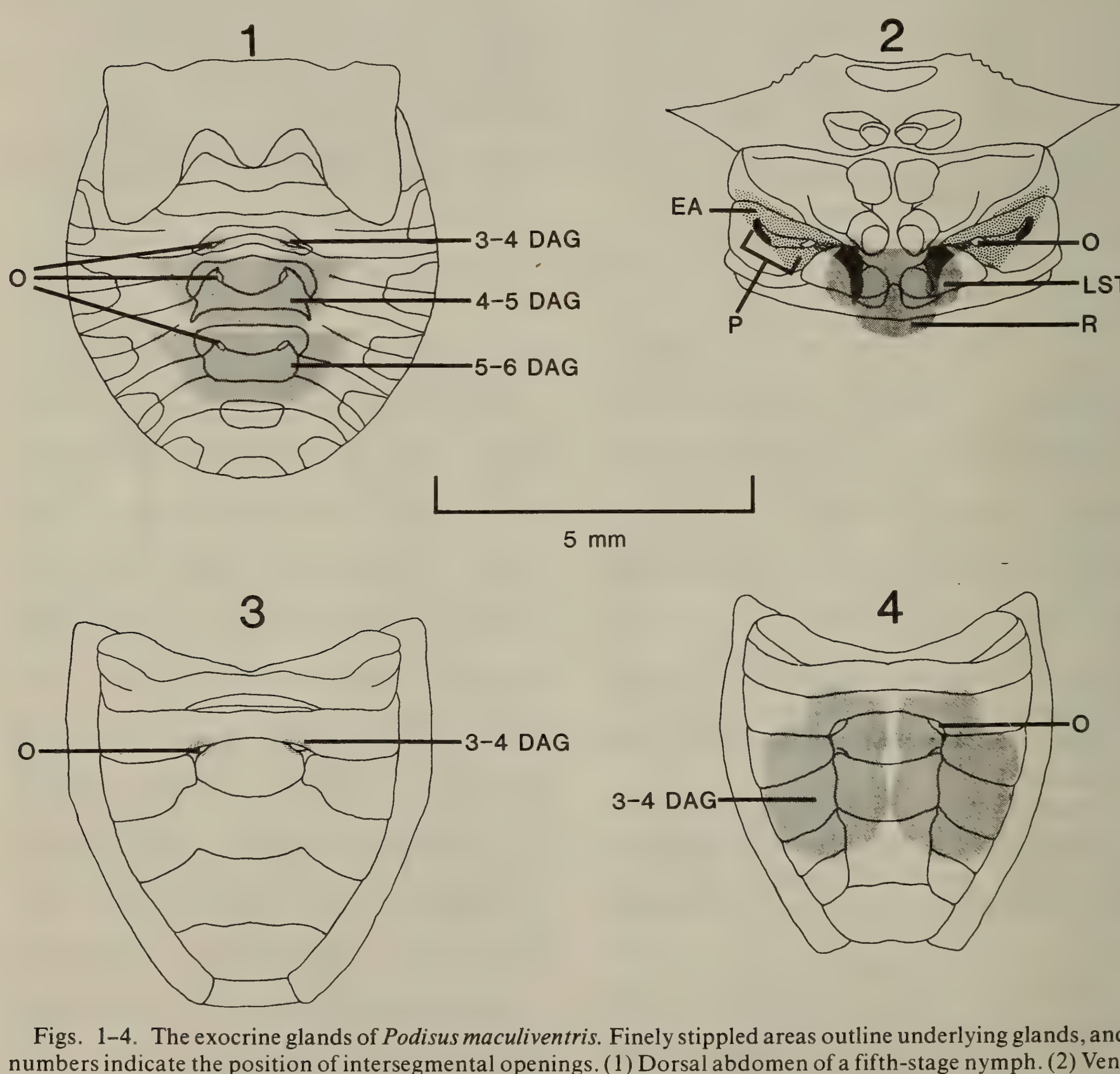
Methods and Materials

A culture of *P. maculiventris* was maintained in the laboratory on *Tenebrio molitor* L. (Rainbow Mealworms, Compton, CA) larvae and pupae.[4] Laboratory-reared bugs were used for all the drawings and chemical analyses.

Figures 1–4, illustrating the dorsal abdominal glands (DAGs) of adults and fifth-stage nymphs and of the metathoracic gland (MTG) of adult spined soldier bugs, were made using a Wild dissecting microscope equipped with a camera lucida.

Details of the preparation of exocrine gland extracts have been previously reported.[4–6] Briefly, exocrine glands were dissected from CO_2-anesthetized bugs submerged in tap water, tissues surrounding the excised glands were removed, and the glands were macerated in 50–200 μl of CH_2Cl_2 or CS_2.

Gas chromatography (GC) of exocrine gland secretions, reported here for the first time (all the nymphal DAG secretions) or re-examined here (MTG and male 3–4 DAGs), was performed on a 14-m-fused-silica capillary column coated with a 0.25-μm film of DB-1™ phase (J & W Scientific, Rancho Cordova, CA) using helium as the



Figs. 1–4. The exocrine glands of *Podisus maculiventris*. Finely stippled areas outline underlying glands, and numbers indicate the position of intersegmental openings. (1) Dorsal abdomen of a fifth-stage nymph. (2) Ventral thorax of an adult showing its metathoracic gland. (3) Dorsal abdomen of an adult female. (4) Dorsal abdomen of an adult male. DAG = dorsal abdominal gland; EA = evaporative area; LSTs = lateral secretory tubules; O = ostiole; P = peritreme; R = reservoir.

carrier gas (linear flow = 40 cm/sec). A Varian 3700 GC equipped with a flame-ionization detector was used with a Shimadzu C-R1B peak area integrator.

Gas chromatographic-mass spectrometric (GC-MS) analyses were conducted using a Finnigan 4500 GC-MS with 30-m columns coated with a 0.25- or 0.1-μm film of DB-1 phase. The GC oven temperature was usually held at 45°C for 2 min and then raised to 255°C at 10°/min. Minor modifications of this temperature program were made for some analyses to improve separations. Electron impact mass spectra were collected at 70 eV with the separator at 240°C and the source at 150°C.

Each compound was identified by comparision of its mass spectrum with the published mass spectrum and/or the mass spectrum of the authentic standard.[7,8] Subsequently, all compounds identified by mass spectral data were cross-checked by comparison of the GC retention of the natural product to that of an authentic standard. Standards of previously identified *P. maculiventris* exocrine components were obtained commercially or synthesized as reported earlier.[4] Tetradecanal was purchased from Aldrich Chemical Company (Milwaukee, WI), and *trans*-piperitol was purchased from PCR Research Chemicals, Inc. (Gainesville, FL). Piperitone (K & K Laboratories, Inc., Plainview, NY) was reduced with lithium aluminum hydride in ether[9] to give a mixture of *cis*-piperitol (29%) and *trans*-piperitol (66%), plus several minor components by GC.

Results

Morphology

Podisus maculiventris nymphs have orange DAGs opening between tergites 3 and 4, 4 and 5, and 5 and 6 (Fig. 1). The 3–4 DAGs are paired and spherical with gland cells surrounding a small cuticle-lined reservoir. Each gland opens exteriorly by a single intersegmental ostiole. The 4–5 and 5–6 DAGs are large, unpaired dorso-ventrally flattened sacs that open exteriorly by a pair of ostioles. The 4–5 and 5–6 DAGs have large cuticle-lined reservoirs with glandular cells confined to their lower walls.[10] All the DAGs have muscularly controlled valves at their ostioles, and the 4–5 and 5–6 DAGs have stretch muscles inserted on the gland sacs, presumably to aid in ejecting the secretions.[10] Apparently, scent emission from DAGs can be independently controlled by these bugs. The contents of the 4–5 and 5–6 DAGs can be forcibly sprayed away from a nymph's body, and the valve-apparatus enables a nymph to aim the spray without moving its body.[10]

At metamorphosis nymphal 4–5 and 5–6 DAGs are inactivated, and only deflated cuticular linings of these glands can be found in adults. The 3–4 DAGs are retained; in adult female bugs, the 3–4 DAGs appear to be identical to those of nymphs (Fig. 3), but in males the 3–4 DAGs are tremendously hypertrophied (Fig. 4). Metathoracic glands (MTGs), which are totally absent in nymphs, are present in both sexes of adults (Fig. 2).

The 3–4 DAGs of male and female adults are paired, orange, and have muscularly controlled ostioles as in nymphs. Although the adult male 3–4 DAGs are larger than the nymphal 4–5 and 5–6 DAGs, they do not have muscles attached to their walls. There is a pronounced sexual dimorphism of the tergal sutures associated with the 3–4-DAG ostioles in adults (Figs. 3 and 4). In females, a suture projects posteriorly from each ostiole connecting the 3–4 and 4–5 intersegmental sutures; the 5–6 and 6–7 intersegmental sutures are not connected by longitudinal stutures (Fig. 3). In males, the longitudinal suture from each ostiole extends posteriorly to the 6–7 intersegmental suture, and tergite 6 is bisected laterally by transverse sutures (Fig. 4). The sutures probably channel secretion laterally from the ostioles.[14] The more extensive system of sutures in males is probably an adaptation to disperse the larger volume of secretion from these 3–4 DAGs.

The MTGs of spined soldier bugs are not sexually dimorphic, but they are morphologically more complex than the DAGs (Fig. 2). The MTG is situated ventrally in the thorax, opening lateroventrally between the meso- and metathoracic coxae. There is a ridge around each ostiole (the peritreme) and a surrounding area of convoluted cuticle (the evaporative area) (Fig. 2, P and EA). The gland consists of two conspicuous parts; an unpaired, orange median reservoir, and a pair of white lateral secretory tubules (Fig. 2, R and LSTs). The lateral secretory tubules are multiply branched tubes formed by gland cells. Each mass of tubules empties into the reservoir through a duct near the ostiole. (Note that in Fig. 2 only the outline of each mass of LSTs is indicated.) The reservoir is lined by cuticle. Its wall contains a variety of evenly distributed secretory cells, and a ribbon-like accessory gland is embedded in the ventral wall.[10] The external MTG ostioles have muscularly controlled valves, but no muscles are attached to the reservoir wall or lateral secretory tubules. The secretion is often exuded onto the evaporative areas when the bugs are disturbed; however, a spray of secretion can be ejected, as well. Apparently pentatomid bugs can aim a spray from the MTG only by adjusting their body positions.[10]

Chemistry

Nymph 3–4 DAGs—These glands are minute and contain relatively little secretion. Of the 4 compounds identified (Table I) in an extract of five pairs of glands from fifth-stage nymphs, (*E*)-2-hexenal was the predominant component. The composition of this secretion is similar to that of adult females.

Nymph 4–5 and 5–6 DAGs—The secretions of these glands from a single fifth-stage nymph can be analyzed by GC.

Table I.—Chemistry of *Podisus maculiventris* exocrine gland secretions[1,2]

Compound	Nymph 3–4 DAGs	Nymph 4–5 and 5–6 DAGs	Adult male 3–4 DAGs	Adult female 3–4 DAGs	Adult MTG
(*E*)-2-hexenal	72.22		45.07	69.33	0.54
(*E*)-2-octenal	10.62			1.24	
(*E*)-2-decenal					10.74
nonanal				0.59	
tetradecanal		1.01			
benzaldehyde	4.69			5.14	
(*E*)-4-keto-2-hexenal		25.73			12.79
(*E*)-2-hexenoic acid				23.70	
(*E*)-2-decenyl acetate					3.42
linalool		28.94	0.83		0.28
(+)-α-terpineol			45.10		
terpinen-4-ol			0.93		
trans-piperitol			1.59		
cis-piperitol			0.07		
benzyl alcohol			6.41		
1-tridecanol					0.02
n-dodecane		0.73			1.54
n-tridecane	12.47	43.58			70.52
n-pentadecane					0.15

[1] DAGs = dorsal abdominal glands, numbers indicate position of intersegmental openings; MTG = metathoracic gland.

[2] Numbers listed in the table are % abundance of a component as determined by peak area from gas chromatograms (nymphal 4–5 and 5–6 DAGs, MTG, and adult male 3–4 DAGs) or reconstructed ion chromatograms (nymphal and adult female 3–4 DAGs).

Comparisons of extracts from the 4–5 and 5–6 DAGs of several individuals showed no consistent differences; therefore, the components identified in these secretions are listed together in Table I. The outstanding feature of these secretions is the presence of the monoterpene alcohol, linalool, as a major component. Tridecane and (*E*)-4-keto-2-hexenal are also major components, but (*E*)-2-hexenal was not detected in these secretions. Tetradecanal is a unique minor component.

Male 3–4 DAGs—Analyses of this glandular secretion have been previously reported[4, 5] and the secretion has been shown to constitute the long-range attractant pheromone of *P. maculiventris.*[5] However, we here revise our earlier report in that the compound tentatively identified as *cis*-piperitol[4] is actually *trans*-piperitol (1.59%, Table I). A compound that coelutes with (+)-α-terpineol using packed GC columns can be separated by capillary column GC and has been identified as *cis*-piperitol (0.07%, Table I). The proportions reported here of previously known components differ somewhat from our earlier reports which used less accurate quantitation methods.

Female 3–4 DAGs—(*E*)-2-Hexenal is the predominant component in the secretion from these glands (Table I). (*E*)-2-Octenal and benzaldehyde were minor components, as in nymphs. Nonanal and (*E*)-2-hexenoic acid occurred in the female 3–4-DAG secretion, but not in that of nymphs.

Adult MTG—The compositions of male and female MTG secretions have been examined earlier and the secretions were not noticeably different.[6] The per cent abundance for the components of the MTG secretion listed in Table I were determined from a single *P. maculiventris* male of unknown age. (*E*)-2-Decenyl acetate is evidently produced only in the lateral secretory tubules,[6] and (*E*)-2-decenal is probably enzymatically derived from the ester inside the median reservoir.[11, 12] The organic secretion in the reservoir is surrounded by an immiscible fluid that is apparently aqueous since it dissolved in the water of the dissecting dish when the reservoir wall was severed. The esterase and dehydrogenase enzymes are thought to be secreted by the accessory gland into the aqueous fluid.[11, 12] Tridecane and the other hydrocarbons are probably secreted by cells in the reservoir wall,[10] but the site of linalool synthesis is unknown. The organic secretion is a mixture of a polar phase and a non-polar phase.[13] The ratio of ester to corresponding aldehyde, as well as the ratio of these compounds to hydrocarbons and possibly linalool, can vary drastically with the age of the bug and the time since the secretion was last emitted. The occurrences of linalool and (*E*)-2-hexenal in this MTG secretion are noteworthy: this is the third exocrine gland secretion of *P. maculiventris* found to contain linalool, here as a minor component, and (*E*)-2-hexenal, which is a major component of all the 3–4-DAG secretions, is present but only as a very minor component.

Discussion

Hemipterans emit chemicals to defend themselves against the attacks of predators[14] and parasitoids.[15] In the spined soldier bug, however, some exocrine secretions are not released in defensive contexts and are compositionally idiosyncratic. Since some, possibly all, of the *P. maculiventris* exocrine blends act as pheromones, this discussion will emphasize the possible pheromonal roles for these secretions and their kairomonal effects.

The chemical vocabulary of *P. maculiventris* is much greater than the list of 19 identified compounds might suggest. Many "minor" components remain to be identified, and surface waxes have yet to be analyzed chemically. Only the fifth-stage nymphs of *P. maculiventris* have been studied in detail; the exocrines of earlier stages may differ.[16] The turnover rates of the various exocrine components are unknown, and, of the optically active components that have been identified, the enantiomeric composition has been determined only for

α-terpineol. Even so, it is clear that *P. maculiventris* nymphs produce at least two unique blends; adults, at least three unique blends. What information might these exudates convey between individuals of the species, and how have other organisms, particularly parasitoids, usurped these signals?

The male 3–4-DAG secretion attracts both sexes of adults, and nymphs are at least moderately attracted to the pheromone.[5] Attracted adult bugs fly to the odor source, and males release this secretion during courtship (JRA, personal observation), so the secretion apparently functions as a long-range attractant pheromone and as a short-range mating stimulant. The natural pheromone contains (+)-α-terpineol, but an artificial pheromone, made with racemic α-terpineol, is as attractive to the bugs as one made with (+)-α-terpineol. Single pheromone components were unattractive to *P. maculiventris* in the field.[17] Whether individual pheromone constituents, including *cis*- and *trans*-piperitol, will elicit particular behaviors has not yet been studied. We believe that wild *P. maculiventris* males, which are usually smaller and mature faster than females,[18] may first search for food and then attract a mate with their 3–4-DAG secretion.

At least four parasitic species sabotage this long-range pheromone system. Females of two flies, *Hemyda aurata* Robineau-Desvoidy and *Euclytia flava* (Townsend) (Diptera: Tachinidae), go the pheromone and lay eggs on the spined soldier bugs they see in the area,[5] sometimes even on other pentatomid species confined near *P. maculiventris* synthetic pheromone (unpubl. data). The male flies are attracted to the vicinity of calling *P. maculiventris* males and appear to defend a territory in order to mate with incoming female flies. Female *Telenomus* n. sp. (Hymenoptera: Scelionidae) are attracted to the male 3–4-DAG secretion and become phoretic on mated female bugs.[5,19] Eventually female wasps oviposit in recently laid *P. maculiventris* eggs.[19] Females of a fourth parasitic species, an ectoparasitic biting midge, *Forcipomyia crinita* Saunders (Diptera: Ceratopogonidae), also find spined soldier bugs by orienting to the male 3–4-DAG secretion.[5] The (−)-α-terpineol in pheromone made with racemic α-terpineol inhibits the response of *E. flava* and *F. crinita* to the pheromone, but *P. maculiventris* and *T.* n. sp. are unaffected by the presence of (−)-α-terpineol.[5]

Neither live female *P. maculiventris*[5] nor synthetic material blended to mimic the female 3–4-DAG secretion attracted bugs or parasitoids. Thus, this exocrine secretion probably acts only over a short distance. Male bugs may recognize a female and/or assess her willingness to mate by the odor of her 3–4-DAG secretion. Parasitoids, especially the *Telenomus* species, might sense near-by female bugs or recognize females they encounter by the smell of their DAG secretions.

Pheromonal roles for the MTG secretion of *P. maculiventris* are, at this point, conjectural. The MTG scent of an irritated *P. maculiventris* adult arouses close-by conspecifics, as in some other hemipteran species;[10] therefore, in this context the secretion seems to function as an alarm pheromone. Since neither the MTG nor its secretion are sexually dimorphic in *P. maculiventris*, a sexual role for this secretion is questionable. The composition of the MTG secretion can vary with age,[11] and this could be important information for courting bugs.

In our airborne trapping experiments, when an adult pentatomid dies, the contents of its MTG rapidly escape from its reservoir. Some scavenging flies (e.g. milichiids) are attracted to hemipteran MTG secretions (Dr. Paula Mitchell, Louisiana State University, personal communication) or to esters similar to those in MTG secretions.[20] This may explain how these scavengers quickly locate dead or injured adult bugs.

First-stage *P. maculiventris* nymphs and many terrestrial hemipterans are highly gregarious, with later stage nymphs becoming progressively more solitary with each molt.[21] Ishiwatari[22, 23] identified (*E*)-2-hexenal in whole body extracts of cabbage bug

nymphs, *Eurydema rugosa* (Pentatomidae), and showed that at low concentrations this compound promoted aggregation of nymphs whereas high concentrations of (*E*)-2-hexenal dispersed aggregated nymphs. Perhaps in *P. maculiventris*, the 3–4-DAG secretion is the short-range pheromone responsible for aggregating young nymphs, and emission of the 4–5- and 5–6-DAG secretions disperses these aggregations. One species of predaceous pentatomid is known whose nymphs hunt singly but recongregate to molt.[21] If *P. maculiventris* nymphs that become dispersed while searching for prey periodically reaggregate, a longer-range aggregation pheromone might have evolved. The occurrence of linalool as a major constituent of the large DAG secretions in *P. maculiventris* may have evolved as part of such a pheromonal message because nymphal DAG secretions usually contain only unbranched compounds.[10]

Tachinid parasitoids may use linalool to locate spined soldier bug nymphs. In preliminary experiments, performed before the nymphal DAG secretions had been analyzed, we field-tested some components of the male 3–4-DAG and the MTG secretions, singly and in mixtures. Four *H. aurata* flies were caught in traps baited with 5 μl of linalool and 5 μl of (*E*)-2-hexenal. *Hemyda aurata* and *E. flava* do sometimes parasitize nymphs in the field.[24] These tachinids may respond to the odor of a provoked nymph or to the odor of DAG components evaporating from the cast skin since the exocrine gland contents are shed at each molt. If tachinid parasitoids were able to home in on the DAG odor from exuviae, this would ensure that eggs are laid on newly molted nymphs and have ample time to hatch before the next molt of the host.

In summary, *P. maculiventris* has an elaborate pheromone system that has been exploited by at least four parasitic insect species. The male-produced attractant pheromone has been most intensively studied; the behavioral correlates for the other exocrine secretions are, at this point, speculative. Future testing of synthetic *P. maculiventris* exocrine blends should answer many remaining questions. Spined soldier bugs are probably not exceptional among Hemiptera in using pheromones—this insect order is a veritable treasure-trove for pheromone researchers.

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Exocrine Secretions of Bees IX. Aliphatic Esters in the Dufour's Gland Secretion of *Synhalonia hamata*#

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ABSTRACT

Chemical analysis of Dufour's gland extracts of the eucerine bee, *Synhalonia hamata*, showed the presence of four acetates. Octadecyl acetate was the major component of the secretions and the C_{16}, C_{20}, and C_{22} acetates were also present. This combination of chemicals in the Dufours gland blend of *S. hamata* is unique.

Introduction

The Anthophoridae is a large, diverse family of widely distributed bees. One of its tribes, the Eucerini, is represented in the United States by approximately 220 species distributed among 15 of the 18 genera represented in North America.[1] *Melissodes* is the largest eucerine genus with close to 100 species represented in North America north of Mexico. *Synhalonia*, another large eucerine genus, is represented in North America north of Mexico by approximately 60 species.[1] They fly primarily in spring and are rarely observed during the summer. Most *Synhalonia* are large, robust, fast flying bees that are native to western USA.

#Hymenoptera: Anthophoridae

Several studies have provided information on the chemistry of the Dufour's gland secretions of the Eucerini. Batra and Hefetz[2] reported a series of acetates including *n*-tetradecyl acetate, dihydrofarnesyl acetate and an isomer of farnesyl acetate of unknown structure in the Dufour's extracts of *Melissodes desponsa* Smith. In comparison, the Dufour's secretions of *Svastra obliqua obliqua* (Say) contain a complex mixture of 32 aliphatic esters. These esters range from a molecular weight of 256 (octyl octanoate) to 508 (tetracosyl decanoate). A series of saturated and unsaturated hydrocarbons ranging from C_{21} to C_{31} were also identified.[3]

As part of continuing comparative studies of the evolution of the chemistry, morphology, and function of the Dufour's

gland, we describe the chemistry of the Dufour's gland secretions of *Synhalonia hamata* (Bradley).

Materials and Methods

Synhalonia hamata were collected at the Marine Training Base at Quantico, Virginia, during June and July, 1983. Bees were netted as they gathered nectar and pollen from *Penstemon digitalis* Nutt. Individual specimens were placed in separate glass shell vials and stored in an ice chest. Dufour's glands were excised under water with forceps, and groups of 25 of them were extracted with methylene chloride.

Extracts were analyzed using a Finnigan 3200 computerized gas chromatograph-mass spectrometer (GC-MS) utilizing a 2.0-m-x-1-mm 3% OV-17 on a Supelcoport 60/80 column, temperature programmed from 60 to 300°C at 10°C/min. Each compound was identified by comparing its mass spectrum and retention time with that of a standard synthesized from the corresponding alcohol and acetic anhydride in the presence of sodium acetate.

Results

One major peak was observed in the Dufour's gland secretion of *S. hamata.* Three minor peaks were also present, one eluting before the major peak and the other two following it. All four were acetates, based upon their base peak at m/z 43 and a peak of m/z 61. Comparison of the retention times and mass spectra of these acetates with those of standard synthetic samples indicated that the major component was octadecyl acetate, proceeded by hexadecyl acetate, and followed by eicosyl acetate and docosyl acetate. Besides the base peak at m/z 43 and the peak at 61(45), peaks at m/z 312(0.1), 252(3), 224(2), 196(1), 168(2), 153(2), 125(20), 111(30), 97(55), 83(65), 69(60), 57(60), 55(65), and 41(35) were useful in the assignment of the structure of octadecyl acetate. Similar peaks were used to assign other acetates.

Discussion

The Dufour's gland secretions of the Colletidae[4] and Halictidae[5] are characterized by series of saturated and unsaturated macrocyclic lactones, as well as isopentenyl esters in some species of the Halictidae.[6] Macrocyclic lactones also characterize the Dufour's gland of oxaeids.[7] In contrast, the Dufour's gland secretions of the andrenids are characterized by terpenoid and straight chain aliphatic esters.[8,9] Those of the Melittidae contain monounsaturated alcohols as well as a series of acetates and butanoates.[10] For a review of the chemistry of bee Dufour's glands, see Duffield *et al.*[11]

In the Anthophoridae, the Dufour's gland chemistry has been investigated in four genera representing two subfamilies. The Dufour's glands of *Xylocopa virginica texana* Cresson and *X. micans* Lepeletier (Xylocopinae: Xylocopini) contain a series of saturated and unsaturated hydrocarbons.[12,13] A series of triglycerides has been identified in *Anthophora abrupta* Say (Anthophorinae: Anthophorini).[14] The Dufour's extract of *Melissodes desponsa* (Anthophorinae: Eucerini) contains terpenoid and straight chain acetates,[2] whereas the Dufour's glands of *Svastra obliqua obliqua* (Eucerini) contain a complex mixture of 32 aliphatic esters as well as saturated and unsaturated hydrocarbons.[3]

At present, the Dufour's gland chemistry of *S. hamata* appears to be distinct from other bees. Although acetates are not uncommon as natural products of bees, the alcohol portion in *S. hamata* is longer than in most. For example, a series of acetates (C_8-C_{14}) has been identified in the cephalic extracts of several species of *Andrena* (Andrenidae).[15] Similar acetates (C_4-C_{10}) have been isolated from the sting apparatus of worker honey bees, *Apis mellifera* Linn. (Apidae),[16] where they function as alarm releasers. Octyl acetate has been isolated

from the worker sting apparatus in all four species of *Apis*.[17] Hexadecyl, octadecyl, and eicosyl acetates have been isolated previously from male labial glands of several species of European bumble bees.[18–21] The C_{16} acetate has also been isolated from male mandibular gland extracts of the small carpenter bee, *Ceratina cucurbitina* Rossi (Xylocopinae: Ceratini).[22]

Acetates appear to be a common group of compounds found as glandular products of bees. They have been isolated from mandibular glands, labial glands, sting glands, and Dufour's glands. The four acetates isolated from *S. hamata* appear to represent a unique Dufour's gland blend among bees reported in the literature.

The functions of acetates as glandular products of bees are diverse. Male labial gland secretions of bumble bees are used as territorial markers.[18] In contrast, the sting shaft glandular secretions of worker honey bees function as alarm pheromones.[16] The mandibular gland products of *Ceratina* appear to be effective defensive allomones against ants.[22]

It has been demonstrated that the Dufour's gland secretions of bees are used to line the brood cells in Andrenidae,[23] Anthophoridae,[14] Colletidae,[24] and Halictidae.[6] Norden *et al.* have observed *Anthophora* larvae ingesting their cell wall linings.[14] Dufour's components have been identified in the larval pollen and nectar provisions of *Augochlora pura pura* Say (Halictidae).[6] Many authors believe the Dufour's gland secretions have some antimicrobial activity, thus increasing larval survival, as discussed by Cane *et al.*[25] We are presently investigating the functions of the acetates in the Dufour's gland secretions of *Synhalonia hamata*.

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The Effects of Population Density on Patterns of Resource Utilization by Yarrow's Spiny Lizard*

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ABSTRACT

The influence of population density on patterns of resource utilization was examined using small enclosed populations of adult *Sceloporus jarrovi* in which density was varied from normal to four times normal. Censuses of active lizards were conducted three times per day; location, time, perch substrate, perch light condition, perch height, and perch diameter were recorded for each lizard. Stepwise multiple discriminate analysis revealed differences along time and perch gradients. At higher densities, animals were active throughout the day and spent more time in the shade and less in the sun. At higher densities, they shifted perch substrate selection from normally-preferred rock substrate to log and ground substrates. Significant differences among density groups were not found in selection of perch height or diameter. The observed differences in patterns of resource utilization may act to reduce the effects of competitive interactions since no significant differences in weight gain among groups were observed.

The importance of behavioral studies for ecology is evident in recent plethora of articles and books concerned with such studies.[1,2] Many of these writings focus on how animal inter-relationships often affect patterns of resource utilization and the converse, how resources affect the ways animals relate to one another. As shown by many recent publications, the behavior of animals is closely tied to their ecology. While behaviorists generally focus on the behaviors exhibited by individuals and ecologists on the behaviors exhibited by a species, behavioral ecologists focus on the impact individual flexibility has on ecological processes. Ecologists, for instance, usually define a species' role in its community by focusing on patterns of resource utilization. Two different, general approaches are used: comparisons of different populations and manipulations of the same population. Comparisons of geographically distinct populations reveal the effects of resource availability,[3,4] seasonality,[5,6] and community composition[7,8] on resource utilization patterns. Experimental manipulations of local populations show that both interference and exploitative competition influence utilization patterns.[9-13] Crowell[14] and Roughgarden[15] have suggested that population density should influence utilization patterns. Studies by McClure,[16] Whitham,[17]

*Sauria: Iguanidae

and Alford and Crump[18] have addressed the effects of density, but have only examined distribution effects. In this paper I shall show that population density affects a number of other aspects of patterns of resource utilization as well.

Traditionally, the dimensions of food, space, and activity time are used to define lizard niches. Measurements include activity time, perch substrate, perch height, perch diameter, and perch light condition. Intensive invesitgations[19–21] of patterns of resource utilization by *Sceloporus jarrovi* show that these lizards partition food, space, and time on the basis of size and sex. Alterations in the availability of food[22,23] and in the thermal environment[24,25] result in adjustments in activity time and perch site selection. Such flexibility makes this species ideal for studying the effects of population density. By varying density of populations one can assess changes in patterns of resource use. In 1976, I tested the hypothesis that variations in density would have no effect on patterns of time and space utilization by lizards. Since direct assessment of density effects on food selection would have involved killing the animals or handling them excessively, I assessed the density effects on this dimension indirectly by examining changes in their weight over the duration of the study. Here, I hypothesized that the limited availability of food for animals at high density would result in alterations in their patterns of resource utilization; if it did not, animals at high density should show less weight gain than animals at low densities. I tested this the following year and showed that animals in high-density populations (3.5 times normal) given supplementary food gained significantly more weight than unsupplemented animals at the same density.[26]

Methods

During the summer of 1976, four populations of *Sceloporus jarrovi* were placed in 17-x-17-m enclosures constructed of polyethylene plastic.[27] One of four density conditions was randomly assigned to each enclosure: normal, 2X, 3X, and 4X. Areas the same size as each enclosure normally support approximately four individuals (two males and two females with overlapping territories between the sexes); densities thus ranged from four to 16 animals per enclosure or about 138 to 554 lizards per ha.

The four enclosures were located adjacent to one another and did not differ appreciably in general appearance. In each enclosure I mapped all rocks, logs, and trees. Since *S. jarrovi* normally perches on large rocks or rock piles, I assessed the availability of these sites in each enclosure and, where necessary, constructed artificial sites such that the number available in each enclosure was equal.

Adult *S. jarrovi* (Snout-vent length > 50 mm) captured from nearby areas were individually sexed, measured, toe-clipped, paint-marked, and assigned randomly to the enclosures with the restriction that there be an equal sex ratio of different-sized lizards. During the study, a few lizards either escaped or died, so they were replaced by animals of the same sex and approximately the same size. Because of time constraints, sufficient data were not collected on some of these animals; therefore, they were excluded from the analyses.

Data collection. Activity censuses were made at different times throughout the day from mid-July to mid-August such that all portions of the day were equally covered. During each census, a search was conducted in every enclosure. Time, location, perch substrate, height, diameter, and light condition were recorded for each active, i.e. visible, animal. Depending on the number of animals spotted, the procedure took from 10 to 45 min. Because animals became accustomed to my presence and were quite visible, I feel certain that few active animals were missed.

The data for each individual were summarized following the format listed below:

1. Substrate. The relative frequency of association with each of the following

substrate categories was determined: rock, tree, ground, and log.

2. Light condition. The proportion of time spent in each of the three following categories was calculated: sun, filtered sun, and shade.
3. Time of activity. The frequency of activity within each of the following time periods was determined: 0800–1100, 1100–1300, and 1300–1600 hours. Proportions for 1, 2, and 3 were normalized using an arcsine transformation.
4. Perch height. Average perch height was determined, excluding all ground observations.
5. Perch diameter. The diameters of all perches utilized by lizards were averaged for all substrates, except the ground.

Data analysis. To identify the variables significantly affected by population density, analysis of variance was run as the first step of the discriminant analysis. The data were then analyzed using stepwise multiple discriminant analysis (SPSS).[28-30] This method allowed for testing of the overall difference among several group centroids. Overall differences among the four densities were tested using Wilks' Lambda statistic. This statistic allows the testing of equality of group centroids and is often converted to the equivalent F or X^2 value. When, and if, significant differences are found, one may then examine the directions of these differences and the variables which contribute to the differences. The method enables the development of a set of variables that can be used to predict group membership and provides a profile of characteristics for distinguishing between groups.

The basic assumptions of multiple discriminant analysis are that variables exhibit multivariate normal distribution and that equal variance-covariance matrices exist between groups.[30] Green[31] notes two further assumptions: one, the groups must be defined a priori and, two, the postulated orthogonal discriminant functions are linear functions of the original correlated parameters. In this study, groups were defined a priori and original parameters transformed to minimize nonlinearity and improve normality. However, because of the categorical nature of several of the variables, it was necessary to summarize the data for each individual. As a result, for some groups the number of variables exceeded the number of individuals in the group. Thus, the final data matrix could not be tested for homogeneity of covariance and could result in a violation of one of the assumptions mentioned above. Because the test is very robust, the assumptions may be violated. As Green[31] states with respect to situations of this type, the assumption of homogeneous within-group matrices is unlikely to be satisfied with ecological data, but if the overall test is highly significant, if the discriminant function coefficients are ecologically interpretable, and if distinct separation occurs among the groups on each discriminant function, then it is reasonable to conclude that the differences are greater than would be produced by drawing random samples from a multivariate swarm.

Results

Analysis of variance indicated significant differences among groups for 58.3% (7/12) of the variables (Table 1). Examination of light condition, activity time, perch height, and perch diameter revealed that differences in resource utilization patterns changed markedly as density increased. Significant differences existed among the four densities with regard to substrate use (Figure 1). Animals at higher densities were observed to shift from rock substrate to tree, log, and ground substrate. At normal density animals were observed on rocks almost 100% of the time, while at 4X animals were observed on rocks less than 50% of the time. Utilization of the three different light conditions also changed as density increases (Figure 2). Animals at high densi-

Table 1.—Univariate F values for each of the discriminant variables.

Variable	Univariate F	Significance Level+
Rock	9.137	***
Tree	3.103	*
Log	6.628	**
Ground	6.128	**
Sun	9.036	***
Filtered Sun	2.033	
Shade	6.362	**
Perch Height	2.910	
Perch Diameter	2.320	
Morning Activity	3.394	*
Midday Activity	0.171	
Afternoon Activity	1.509	

+Degrees of freedom: 3 and 28.
* $p = 0.05$; ** $p = 0.01$; *** $p = 0.001$.

ties were observed more often in shade and filtered sun and less often in full sun than animals at normal density. However, significant differences were observed only for sun and shade conditions. Perch height and perch diameter selection showed no significant differences. While significant differences among the groups were observed only for morning activity, the patterns of daily activity appear quite different (Figure

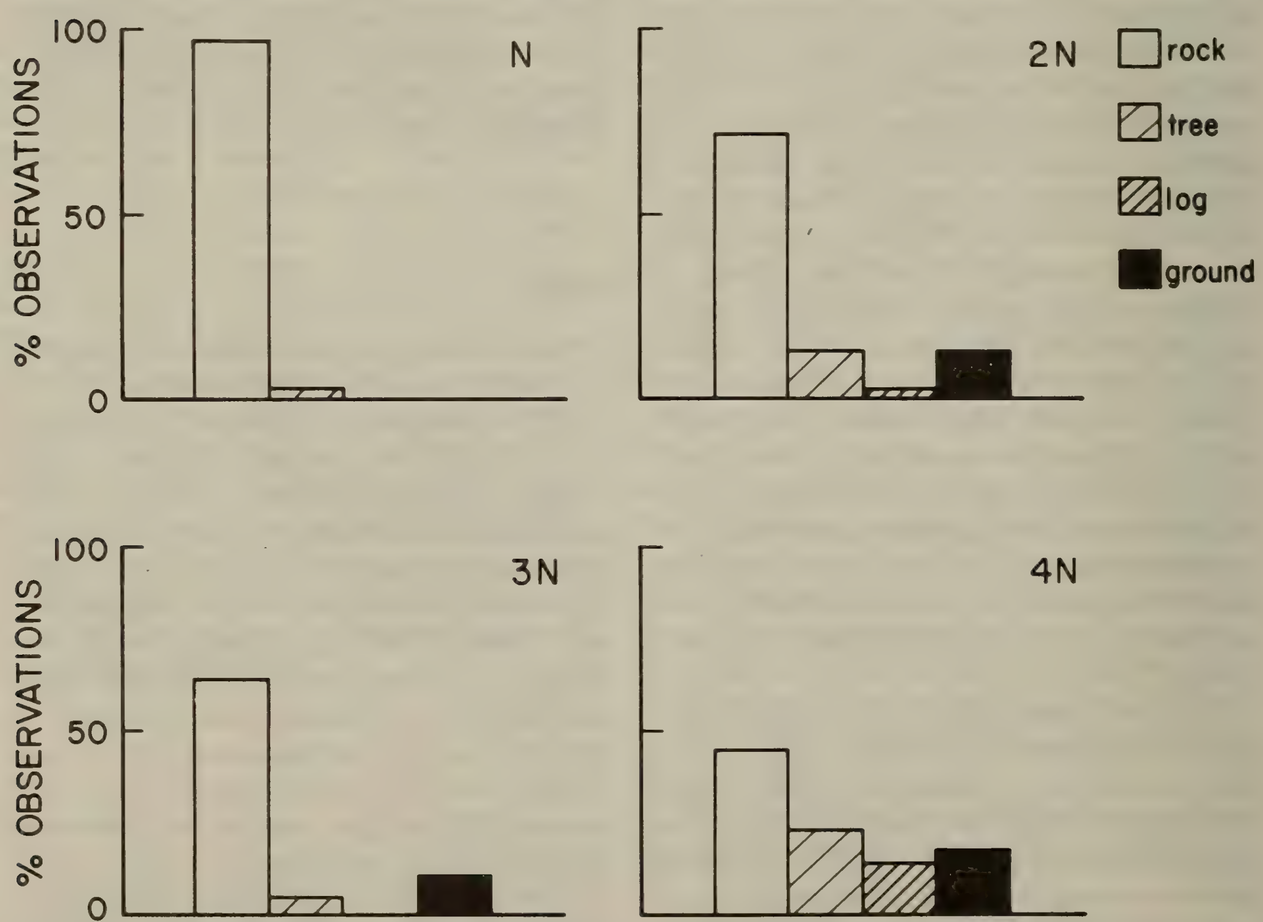

Fig. 1. Mean percent observations of individual *Sceloporus jarrovi* on different substrates as a function of density level.

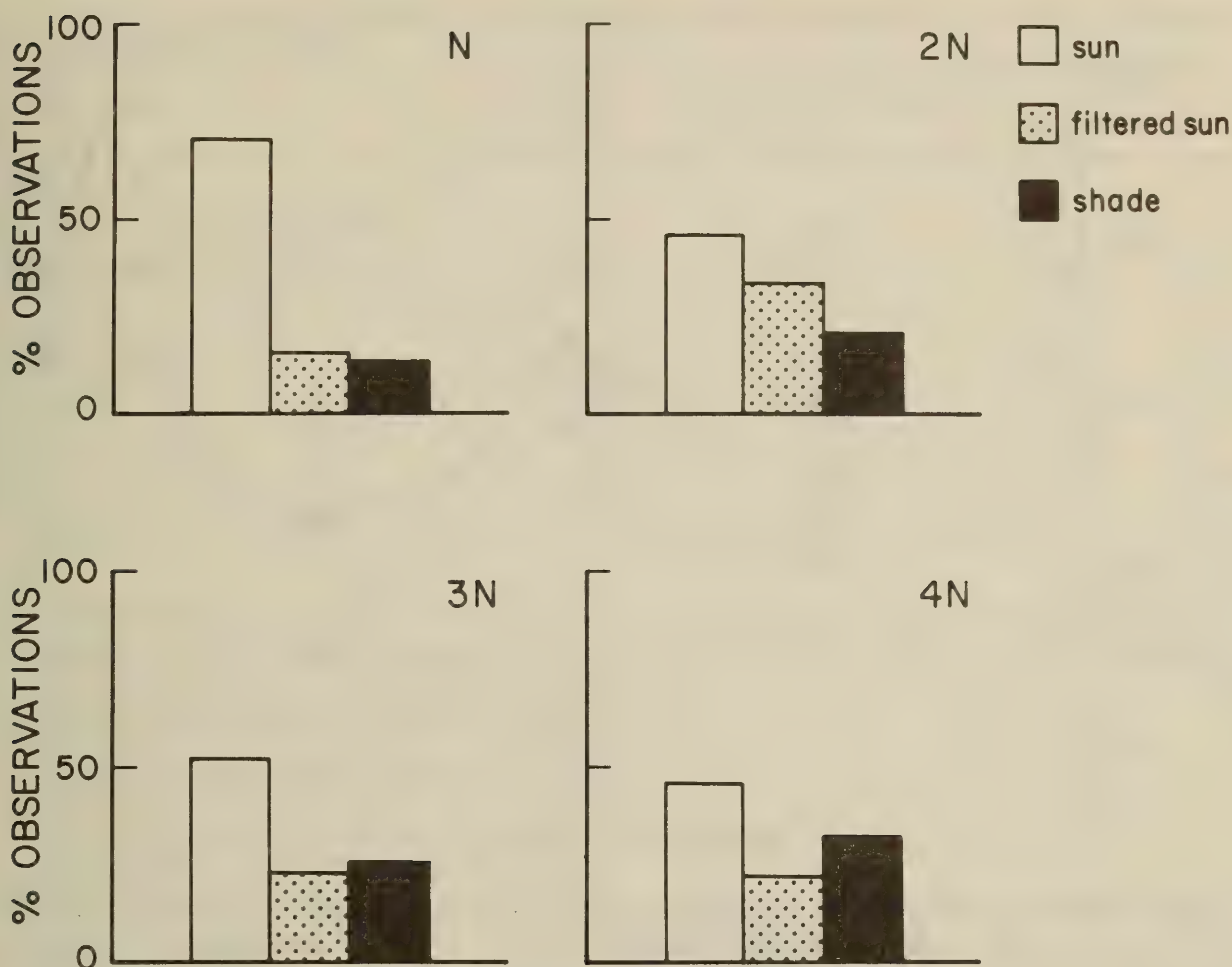

Fig. 2. Mean percent observations of individual *Sceloporus jarrovi* in different light conditions as a function of density level.

3). At higher densities activity was even throughout the day, as opposed to the "peaked" activity observed at normal density.

The measured variables significantly discriminate among the different densities; Wilks' Lambda was calculated to be 0.0862 and is equivalent to an F value of 5.02 with 18 and 65.54 degrees of freedom. The probability of obtaining such an F value is <0.0001. The untransformed means and standard deviations for each variable at each density are shown in Table 2.

The first discriminant function (DF1) accounts for 57.4% of the relative variability among the densities (Table 3). This function seems to reflect both perch selection and thermal influences as it is primarily formed from the rock and shade variables, as seen by the weighting factors or standardized discriminant function coefficients (d_i's) for the variables. Separation is achieved because animals at normal density spend more time on rocks and less time in the shade than those at higher densities, particularly at the highest density.

An additional 28.6% of the relative variability was accounted for by the second discriminant function (DF2) which centered on thermal influences, as seen by the large contribution of the sun variable in the weighting coefficients (Table 3). Separation along this function was complex, as perch diameter, morning activity and afternoon activity were also influential. Animals at normal density were seen in the sun more often than those at higher densities. Note that normal density animals concentrated their activity during the midday period (Figure 3); because of low density, these animals may have been able to move about more easily and, thus, thermoregu-

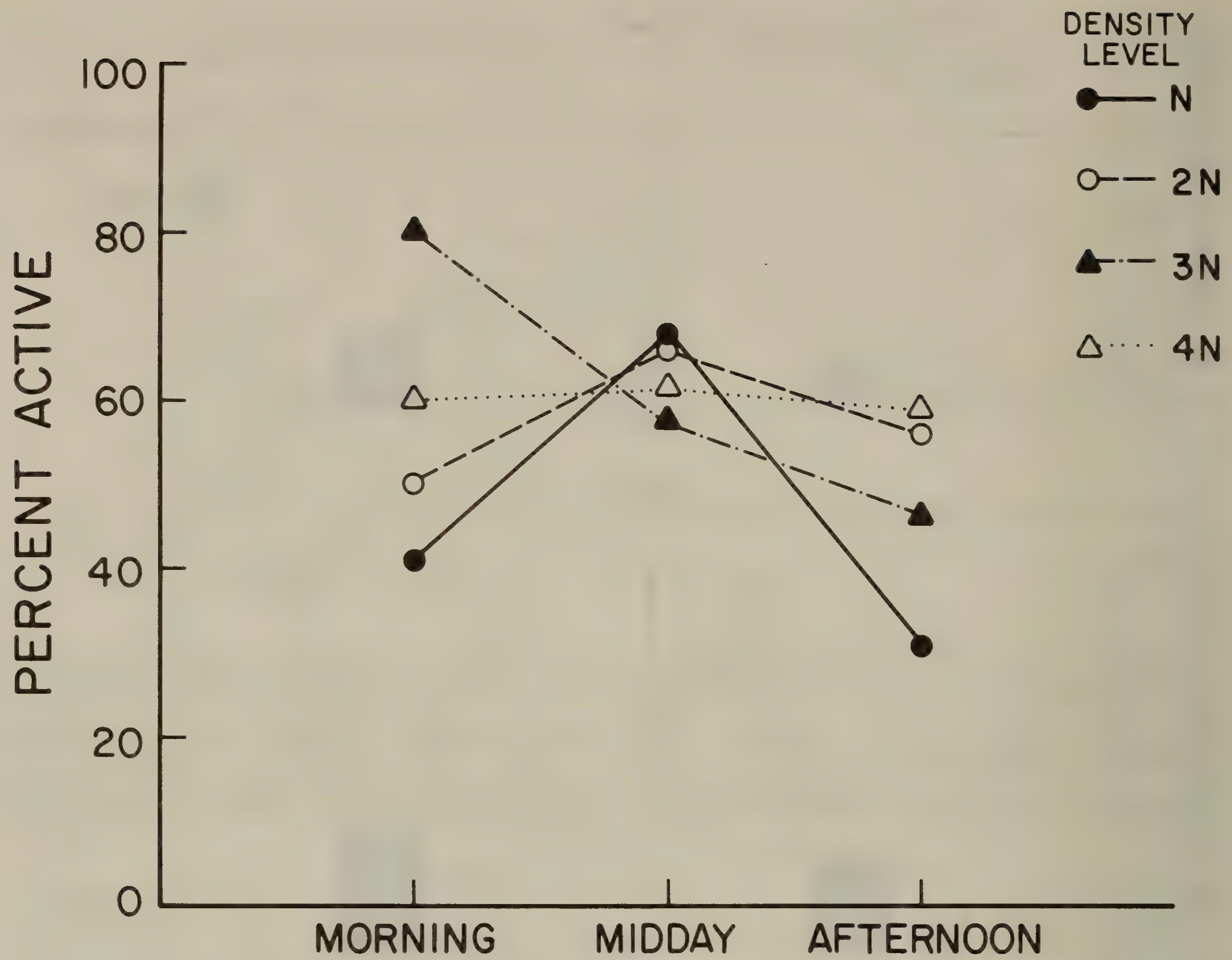

Fig. 3. Mean percent activity of individual *Sceloporus jarrovi* as a function of density.

Table 2.—Untransformed means of the microhabitat variables for each density level. Mean and one standard deviation, in parentheses, are indicated. All refer to unit fractions unless otherwise indicated. Activity is measured as percent population active during the census period.

Variable	Density Level Normal	2X	3X	4X
Rock	0.97(0.06)	0.72(0.18)	0.64(0.13)	0.45(0.25)
Tree	0.03(0.06)	0.13(0.21)	0.05(0.13)	0.23(0.17)
Log	0(0)	0.02(0.03)	0(0)	0.14(0.15)
Ground	0(0)	0.13(0.12)	0.11(0.08)	0.18(0.11)
Sun	0.70(0.09)	0.46(0.10)	0.52(0.07)	0.46(0.09)
Filtered Sun	0.16(0.10)	0.33(0.09)	0.23(0.09)	0.22(0.13)
Shade	0.14(0.01)	0.21(0.09)	0.25(0.11)	0.32(0.08)
Height (meters)	0.32(0.11)	0.29(0.06)	0.28(0.07)	0.46(0.21)
Diameter (cm)	0.38(0.11)	0.31(0.08)	0.32(0.05)	0.40(0.09)
Morning Activity	0.41(0.21)	0.50(0.21)	0.80(0.25)	0.60(0.22)
Midday Activity	0.68(0.14)	0.66(0.21)	0.58(0.20)	0.62(0.29)
Afternoon Activity	0.31(0.10)	0.56(0.09)	0.47(0.22)	0.58(0.29)
Sample Size	4	6	6	16

Table 3.—Standardized discriminant function coefficients (d,'s) showing the relative contribution of the variables to each discriminant function.

	Discriminant Functions 1	2	3
Percentage of among groups variance	57.42	28.65	13.93
Cumulative percentage	57.42	86.07	100.00
Variables:			
Rock	−0.753	0.072	−0.205
Sun	0.194	−1.165	−0.344
Shade	0.795	−0.402	−0.545
Diameter	0.358	−0.742	−0.420
Morning Activity	−0.172	0.647	−1.046
Afternoon Activity	0.572	−0.636	0.518

late more efficiently. Greater activity in the morning and afternoon periods occurred at higher densities (Figure 3) which explained the contribution of these variables to DF2.

The third discriminant function (DF3) accounted for a further 13.9% of the relative variability and was primarily a function of activity time. Differences for morning and afternoon activity followed the pattern noted for DF2.

Based on the results of the discriminant analysis, approximately 84.4% of all animals were correctly classified (Table 4). The most distinct group was normal density with 100% correct classification, while even the least distinct groups, 2X and 3X, showed 66.7% correct classification. The locations of the centroids for each of the four densities on the first two discriminant axes are shown in Figure 4.

Weight changes among the four densities were not significantly different (ANOVA, $F = 1.49$, $df = 3, 28$, $p > 0.05$, Figure 5).

Discussion

Patterns of resource utilization were clearly affected by population density. This alteration was generally characterized by shifts at higher densities. For instance, animals shifted substrate use from the normally-preferred rock substrate to log, tree and ground substrates. A shift in perch light condition at high densities resulted in increased numbers of animals in filtered sun and shade conditions. Not only were animals observed more often in partial sunlight, but they spent more time in these light conditions than animals at low densi-

Table 4.—Classification results of the discriminant analysis for density using microhabitat variables. Numbers in parentheses represent the actual number of individuals placed in each group. The total percent of individuals correctly classified for all groups was 84.4. Sample size does not reflect density due to deaths and escapes (see text for further details).

Actual Group Membership (density)	n	Predicted group membership (%) Normal	2X	3X	4X
Normal	4	100.0(4)	0.0(0)	0.0(0)	0.0(0)
2X	6	16.7(1)	66.7(4)	0.0(0)	16.7(1)
3X	6	0.0(0)	16.7(1)	66.7(4)	16.7(1)
4X	16	0.0(0)	6.2(1)	0.0(0)	93.8(15)

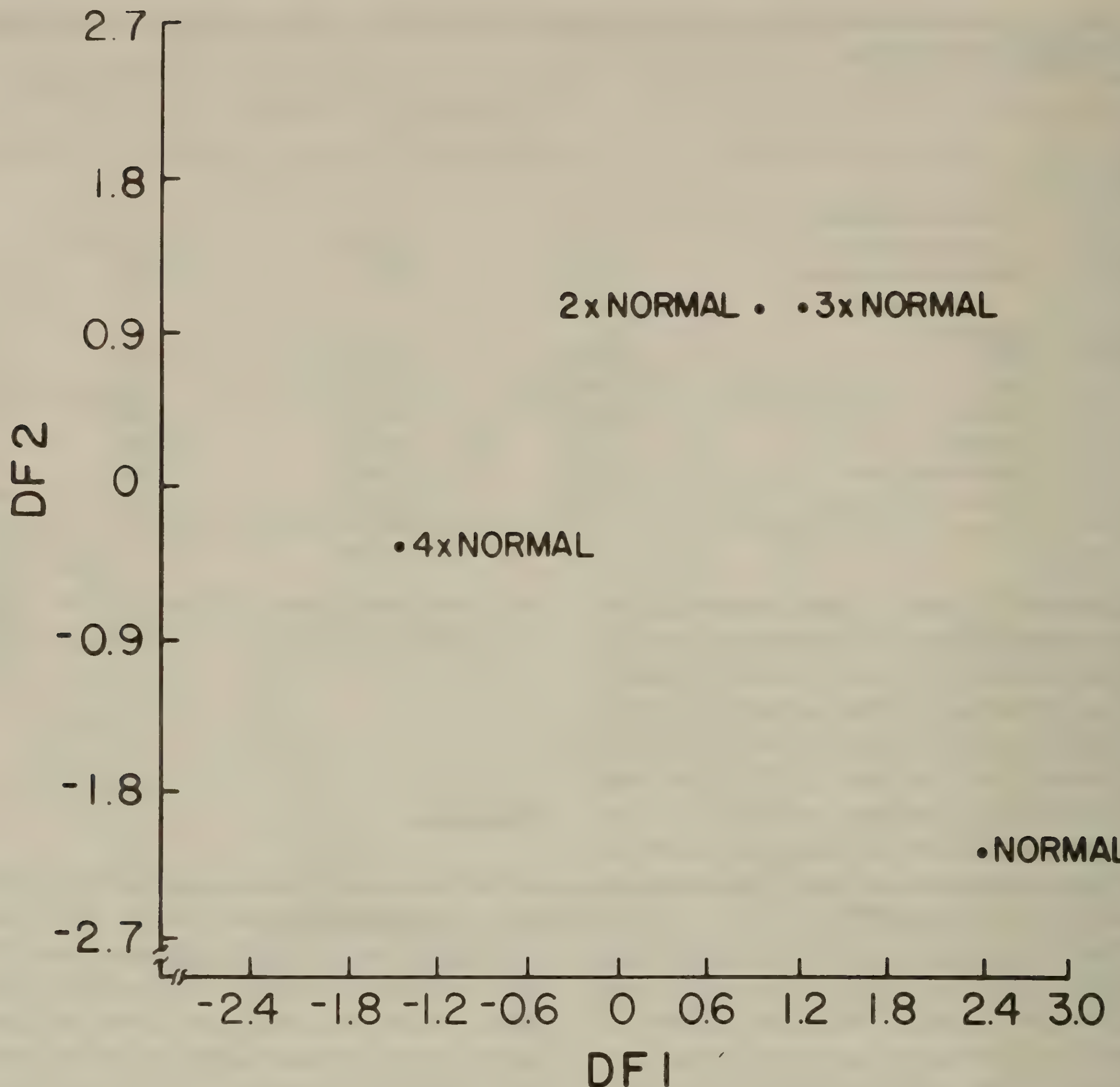

Fig. 4. Centroids of different density groups on the first two microhabitat discriminant axes.

ties.[25] These observations, when coupled with the increased activity throughout the day at high densities, suggest that some of the changes in perch substrate and light condition selection might be due to an increased heat load. Burns[24] reported a shift in perch substrate selection by *S. jarrovi* in response to changing thermal stresses associated with afternoon activity; animals moved to higher perches in trees to increase convective heat loss. Other studies reporting changes in activity time by *S. jarrovi*[21,23] show little change in perch substrate selection; none of the changes in activity time, however, were as marked as those observed in this study.

Perch selection with regard to diameter and height showed no significant differences in response to changes in density. Although other studies of *S. jarrovi* have shown alterations in perch height as a function of food availability,[23] the present results suggest that perch utilization patterns are relatively insensitive to alterations in population density.

The absence of significant differences in weight gain for the animals in the four densities strongly suggests that lizards at high density alter their patterns of food utilization. Normally, *S. jarrovi* forage early in the morning and have full stomachs by about 1100 hours,[20] suggesting that the increased activity in the morning and afternoon by high-density animals may allow

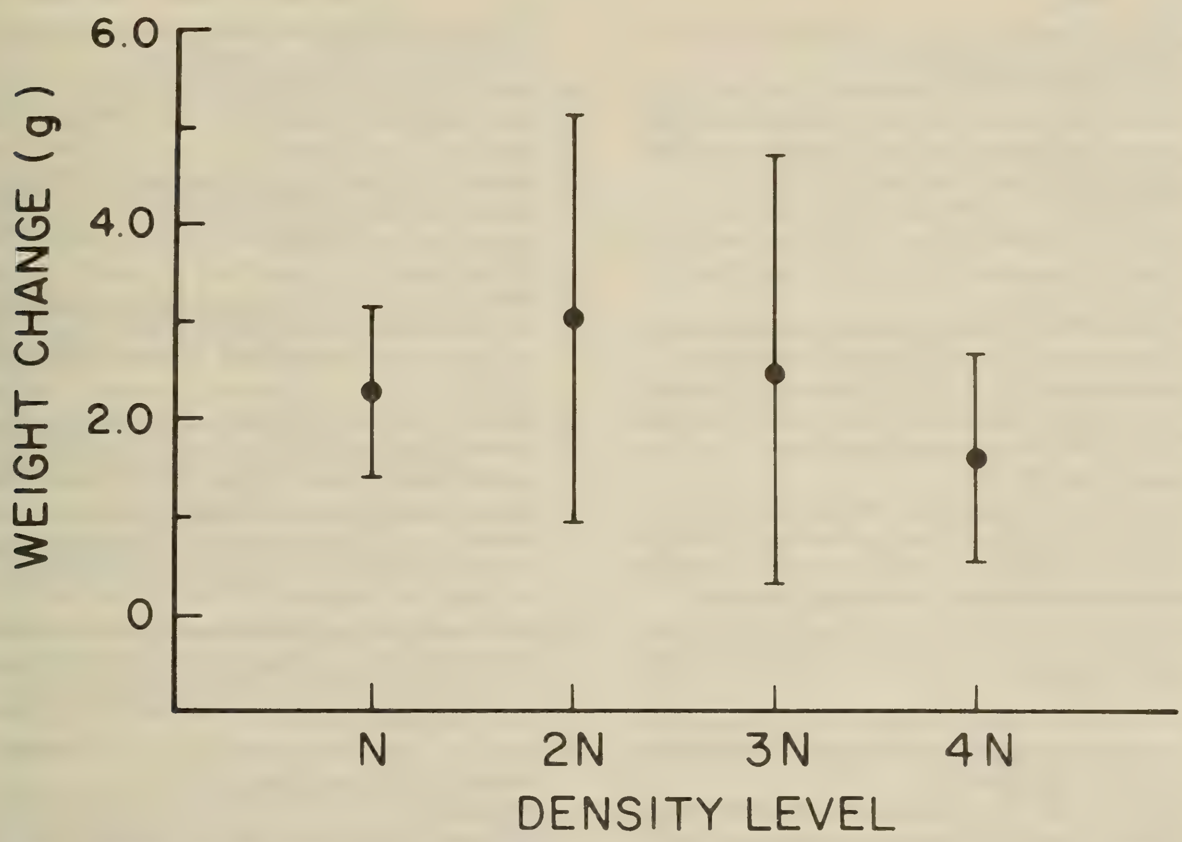

Fig. 5. Weight changes of *Sceloporus jarrovi* as a function of density level. The means and one standard deviation are indicated.

them to forage throughout the day and thereby obtain enough food. Their alterations in perch substrate and perch light condition selection may act to reduce thermal stresses associated with day-long activity and thus allow the animals to remain active.

Clearly the behavioral flexibility exhibited by *S. jarrovi* aids in adjusting the animals to potentially stressful situations. To say that such behavior is adaptive would not, in this case, be presumptuous; alterations in patterns of resource utilization to increased densities up to four times normal that result in non-significant differences in weight gains over a 6-week period must be adaptive.

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ERRATA

In Volume 74, Number 1 of the Journal, the name of the Academy's Executive Committee was inadvertently misprinted. This has been corrected in the current issue. We apologize for the error.

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Commentary

Why It's So Important that Our Students Learn More About Science

V. V. Raman

A world exposed to a scientific value system could be a world with less dogmatism

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MANY PRESTIGIOUS GROUPS, including the National Commission on Excellence in Education, have lamented the sorry plight of science education in this country. They all warn us that, unless we correct the situation, it will not be long before the Europeans—and what's even more serious, the Soviets—will overtake us in science, if they haven't already.

A great deal of impressive data have been amassed to show that we have been neglecting science education for some time. Invariably such data are related to the numbers of science graduates and teachers as well as to the average test scores of science students.

We must produce more science graduates and engineers, the argument goes, because unless we train enough people in those fields, there will be disastrous consequences in vital facets of our technology and defense capability. We need scientists and engineers to push forward the frontiers of technology so that our industries can turn out more competitive products, and more and better military hardware to keep the country safe from foreign aggressors.

I am not concerned here with the merits of such goals and concerns; obviously, to keep a technologically sophisticated society functioning properly we need technically well-trained people. But I do not question the notion that we need to teach our students good *science* to accomplish the goals or to respond to the concerns. Technical skills and useful information, yets; but not necessarily science.

Indeed, our enormous technological progress has resulted not from teaching good science but rather because many ingenious people have been able to exploit scientific knowledge and manage the business end of it as well. It is entirely possible for a thriving and militarily strong industrial society to function successfully with a sizable cadre of technically trained people at various levels who may be as unscientific in their extra-professional lives as anyone else.

It is naïve to think that the millions who are engaged in the myriad scientific and technical projects in this country are all scientific in any serious sense of the term. Science is not required to handle or solve specific technical problems.

That a strict scientific training is not indispensable for contriving useful gadgetry is amply illustrated in the lives of many competent inventors. From Savery and Newcomen to Edison and the orignators of air-conditioning and the helicopter, there have been any number of imaginative and ingenious people who have contributed significantly to the advancement of technology. Conversely, there are some illustrious names in the history of science—Copernicus and Huygens, Pauli and Bohr, to name just a few—who were not directly associated with any major engineering device.

Science as an intellectual enterprise has had little impact on the way people in general look at things. It is a sad but not surprising spectacle when well-meaning science teachers and others argue in this day and age from medieval and more ancient perspectives. Respectable school systems are urged to teach mythologies in science courses, because many parents and teachers are convinced that ancient views on the origins of life or of the planet have the same validity as any modern scientific theory. At the other extreme, in some societies so-called scientists have argued that everything from the theory of relativity to the quark model are confirmations of Marxist-Leninist theology.

These would be merely amusing instances of human folly were it not for the fact that looking to dogma for ultimate and unalterable truths about the world and history has often led to rigid and belligerent idealogies that have wrought much harm and ill will among peoples. A fanatical conviction that one's chosen way is the only route to celestical Paradise or terrestrial utopia has been at the root of many international conflicts.

What has all this to do with the teaching of science? I contend that science should be taught not simply as a body of useful knowledge clothed in technical vocabulary but as a mode of inquiry into the nature of the perceived world, as an intellectual framework to guide us in the adoption of tentative interpretations of what is observed, and as a world view that is not ultimate truth but is applicable and acceptable only in the context of a given set of available facts. If that point of view is also encouraged in situations beyond technical problems, we may see a world where there is less dogmatism and greater mutual understanding.

Science should be taught because of the value system it fosters, because of its criteria for the acceptance of points of view as valid propositions—not because of its potential exploitable results, or even for its beautiful and powerful theories. Science taught without reference to the scope and limits of human knowledge, without alluding to the collective nature of the enterprise, is incomplete.

INDIVIDUAL SCIENTISTS are not always reasonable, of course, nor are they always exclusively motivated by the highest ideals in their quest for truth. The irrationality and self-serving strategies of many scientists, from Galileo and Newton to more recent members of the scientific community, have been amply exposed by historians and philosophers of science. Yet as a collective enterprise, science is a model of dispassionate exploration and objective analysis—more so, perhaps, than any other human endeavor.

To challenge the teacher or a text, to raise questions and objections until one is fully satisfied, to reject unsubstantiated propositions—even if they come from the highest authorities—these are among the attitudes we need to develop while teaching science.

It is our failure to do so that makes possible the appalling paradox of the twentieth century: the indiscriminate acceptance of medieval—and sometimes pernicious—world views by the masses in many societies, including our own. Not one in a million take seriously the inane predictions corresponding to their birthdays that are published in magazines and newspapers. To say nothing of numerology or the pseudo-psychologies and pseudo-religions with mantras that dupe the multitude.

The reasons for this situation are twofold. On one hand, the scientific world view is not only difficult to comprehend in its de-

tails, it is also far less reassuring than more simplistic and homocentric versions of the universe. On the other, formulas and principles, rather than scientific outlook and critical analysis, are generally taught in our science courses.

The spiritual and aesthetic components of the scientific quest are usually neglected in favor of the practical. Efforts must be made to convey to students the thrill and excitement associated with new discoveries, the beauty and harmony of physical laws, the mind-boggling vastness and also the minuteness that constitute the universe, the ultimate simplicity and order underlying scientific processes, the frustrations and triumphs of individual scientists in their struggle to unravel a secret of nature.

The Copernican revolution kicked man off the center of the universe. Later, even our sun was shown to be an insignificant speck at the edge of a grand galaxy that in turn is but one of billions in the vast expanse of void. There would seem to be no greater deflater of the ego than the revelations of astronomy. A little reflection, however, should reassure us that we are not all that insignificant.

AS FAR AS WE KNOW, no star ever speculates on the birth and death of human beings; no galaxy computes its distance from Earth; no quasar compares its mighty energy with that of our sun; and there is no pulsar or black hole, no nova or galactic center that is concerned with the human condition.

Yet the human mind has penetrated the most distant recesses of space and time, and the most subtle palpitations of physical reality. Aside from electromagnetic radiation, only the human mind is capable of bringing together the past and the present, the near and the distant elements of the universe.

All this suggests our pre-eminence in the cosmos, fleeting though it may be. It reminds us that our true glory lies not in our physical dimensions or cosmic location but in our intellectual and spiritual capacties—to think and probe, to feel and reflect, to experience joy and sorrow. We have been made aware of such basic truths most effectively by science. It will be unfortunate if that insight is not experienced by our students—all the more so now, when the myopic equate science with nuclear bombs, acid rain, and pollution.

Scientific appraisal invariably transcends cultural and nationlistic narrowness, puts parochial claims of religious distinctiveness in their proper perspective, and reveals the absurdity of racial and sexual prejudices. If we can enrich the awareness resulting from such appraisal by encouraging our students to develop respect, compassion, and consideration for other human beings, how fruitful our educational efforts will prove to be.

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High Technology, Can Higher Education Meet the Challenge[1]

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In order to better understand the interrelationships of high technology and education, it is important to understand the requirements for high technology and the state of America's colleges and universities in the 1980s.

Technological development is based primarily on individuals with basic backgrounds in science, engineering and related fields. Peter Drucker[2] in a discussion on applied science and technology, suggests "Technology is not then the application of science to products and processes as is often asserted—at best, this is a gross oversimplification. In some areas for example, Polymer chemistry, pharmaceuticals, atomic energy, space exploration and computers, the line between scientific inquiry and technology is a blurred one. The scientists who find new basic knowledge and the technologist who developed specific products and processes are one and the same man. In other areas, however, highly productive efforts are still primarily concerned with technological problems and have little connection to science as such.

"In the design of mechanical equipment, machine tools, textile machinery, printing presses, scientific discoveries as a rule play a very small part and scientists are not commonly found in the research laboratory. More important is the fact that science, even where most relevant, provides only the starting point for technological effort. The greatest amount of work on new products and processes comes well after the scientific contribution has been made. Knowhow in the technological contribution takes a good deal more time and effort in most cases than the scientists know what. But science is not a substitute for today's technology, it is the base and starting point."

Peter Drucker[2] points out technological research has not only a different methodology for invention, it leads to a different approach known as innovation or the purposeful and deliberate attempt to bring about through technological means a distinct change in the way man lives. Innovation may begin by defining a need or an opportunity, which then leads to organizing technological efforts to find a way to meet the need or to exploit the opportunity. To reach the moon, for example, required a great deal of new technology. Once the need had been defined, the technological work was organized systematically to produce the technology.

Innovation can proceed from new scientific knowledge in the analysis of the opportunities it might be capable of creating.

Innovation is not a product of the twen-

tieth century. Edison was an innovator as well as an inventor. It is only, however, in the twentieth century and largely through the research laboratory and its approach to research that innovation has become central to technological effort. Innovation technology is used as a means to bring about change in education and in the economy. Thus, modern technology influences traditional society and culture, but innovation means that technological work is done not only for technological reasons, but also for non-technological reasons.

High technology requires not only the inventor or innovator or the entrepeneur, but development requires the finances or the venture capitalist. No cash means trouble in any industry. The new company is not yet producing or selling a product so the marketplace cannot pass judgment on the company's activities or products.[3]

A company and the venture capitalist hope the product makes a splash in the marketplace and sizeable profits will be realized.

In a Wall Street Journal article[4] in August of this year Ed Zschau and Don Ritter, the Chairman and Vice-Chairman of the Republican Task Force on high technology initiatives in the House of Representatives indicated that they believe the government needs to foster an environment in which innovation, new ideas and new companies can flourish. They suggested four conditions are needed for an environment that promotes innovation.

- "A strong commitment to basic research. Deepening and broadening our understanding of fundamental processes will form the basis for industries, processes, and products in the future.
- Incentives for investors, entrepreneurs, and innovators provide the capital and take the personal risks associated with making technological advances, developing new products, establishing new companies and rejuvenating mature industries.
- A strong educational capability, particularly in the sciences that ensures an ample quantity of trained technical and managerial personnel and a broad base of educated and well-trained citizens who can meet the challenges of a rapidly changing world.
- Expanding market opportunities, domestic as well as foreign, require healthy domestic economic environment and aggressive trade policy."

How do the universities fit into this plan for developing entrepreneurs and high technology. Obviously, there is the very vital role of training scientists and engineeres in a modern fashion. It is important to recognize, however, that the number of doctorates in the physical sciences and mathematics have been dropping. For example, in 1950 there were 200 mathematical scientists completing their Ph.D.s which grew to its peak in 1969–70 of 1300; it has dropped back to about 800 with only 61% of the Ph.D.s going to U.S. citizens in mathematics. The same pattern holds true in chemistry and physics[5].

The pipeline of scientists and engineers is also against us. Betty Vetter[6] reports that the number of 22 year-olds will drop 26% between 1983 and 1999. This year and next year's graduating classes will be the largest in history and 25% larger than the class of 1998. The estimate is that currently from seventh grade through college, 4.4% of the men and 1.9% of the women earn a quantitative bachelor's degree. One in ten of the men who earn a quantitative bachelor's degree will go on to a Ph.D. and one in twenty of the women will go that far.

Universities have an added problem besides not attracting the students to science and engineering in large numbers, they are not teaching the students with the latest technology. Some reports have estimated that engineering and science students today are being trained on equipment that is about four generations away from what is being used in the new industries. The National Science Foundation, the Office of Education and other groups have conducted surveys which suggest that probably a billion dollars would be required to provide modern up-to-date equipment for the col-

leges and universities in the basic sciences and engineering. A 1984 survey of university chemistry departments suggests $500 million is needed for Chemistry instrumentation alone[7]. Universities, neither public nor private, have that amount of money to invest. New modern instrumentation for research is very expensive.

Spectrometers of all types, infra-red, ultra-violet, visible, mass are all electronically run with their computers built in. The "simple IRs" that cost $2–3,000 twenty years ago now cost $40–50,000; which is significantly greater than the inflation factor. The whole cost of the instrumentation has escalated dramatically. A simple nuclear magnetic resonance spectrometer to do proton NMR that is designed for routine work, nothing fancy, cost $30,000 four years ago. The company no longer makes the instrument because it would only do routine work and was used only for teaching purposes. A 90 megahertz instrument cost $100,000 about six years ago. The state of the art 500 megahertz instrument is about a half-million dollars without considering the aspects of the money and personnel required to maintain it or the auxillary computers required to process the data.

However, NMR is only one of four or five spectral techniques which most organic and biochemists would employ to do studies on molecular structure. A mass spectrometer (simple version $100,000), IR, UV-Visible, possibly X-ray, atomic absorption, etc., are also required by the organic chemist. The equipment required by the biologist, in modern DNA studies, gene splitting, etc., of course, is even more expensive.

Engineering schools have always been equipment based and have problems greater than the sciences. However, the problems for science and engineering departments of universities go beyond the equipment; personnel is a very key aspect of the whole process. The figures for the Fall of 1984 on the unfilled vacancies in engineering and computer science are not yet available but there is no reason to expect that things will have improved substantially. In 1983 engineering schools across the country had about 10% of their positions unfilled.[8] Computer science faculty in most universities have degrees from either engineering or sciences. Ph.D.s in computer science were not generally offered 20 years ago, but there are special problems with the scientists and engineers who go into computer science because they quickly find life is more lucrative outside academia; academic salaries are simply not competitive with industry. They never have been, but the gap has been widening in recent years. In some state universities while the salaries for faculty may be higher overall than they are in private institutions, many state universities preclude paying differential salaries for marketplace conditions so that added salary cannot be provided to the engineering faculty. Private universities whose salaries are often lower are more likely to pay the added salary for the engineer or scientist but they still simply are not competitive.

Unfortunately, the salary differential has an additional impact on the high school science and math teachers who are well trained and who can find an even greater salary differential. The number of trained science and math teachers leaving secondary education for the industrial marketplace is growing and is a problem that the nation must face and recognize.[9]

The Panel on Technical Manpower Resources[9] reports:

"Today's shortage in engineering faculty comes at a time when the demand for an engineering education is skyrocketing. The Engineering faculty Shortage Project notes that many deans—more than 80% surveyed —report that the quality of instruction has declined: class sizes are reaching unmanageable levels; existing faculty already overloaded have become more so; and the overall system is showing signs of fatigue if not outright collapse. Although engineering graduates may be turned out in appreciable quantities, the quality of their education is being progressively degraded."

The cooperation needed between universities and high tech industries is, of course, best exemplified by Silicon Valley and Stanford University. It is important to recognize, however, that there are certain special characteristics that led to the success of Silicon Valley. First of all, Stanford owned 8,800 acres of land which they could not sell. Stanford administrators were faced with the problem of converting the University land into money.[10]

Stanford, prior to Silicon Valley, was not the great university it is today. The whole concept of Silicon Valley as a high technology industrial park was really the idea of Frederick Terman who was then Vice President of Stanford. Terman said the idea of an industrial park near a university was completely foreign, both to Stanford and to the firms that would become leasees. The first leasee for the Stanford industrial park was Varian Associates who had some rented buildings in San Carlos. In 1951 they signed the first lease for four acres prepaying $4,000 an acre for a 99 year lease. There is no inflation clause in that original agreement and it has been suggested that Varian Associates probably has one of the sweetest land deals in Silicon Valley. Hewlett Packard took a lease in 1954 and became really the lease nucleus for Silicon Valley. Terman would use Packard or Hewlett to talk about the advantages of being close to a university; today there are 90 tenant firms employing 25,000 workers in the Stanford research park.[10]

The park contributed financially to the growth of Stanford in that the prepaid leases provided 18 million dollars which was used to retain and recruit star faculty. In 1981 the annual income was about 6 million dollars per year. The advantage of the income from Stanford Research Park is that is is unrestricted and can be put to any good use by the Stanford administrators.[10]

A very important aspect of the development for Stanford and the use of the funds was Terman's plan for Stanford's assent—the strategy "Steeples of Excellence." His view was academic prestige depends upon high, but narrow steeples of academic excellence, rather than upon coverage of more modest height extending solidly over a broad discipline. Exactly what is a steeple? Terman defined it as "A small faculty group of experts in a narrow area of knowledge and what counts is the steeple be high for all to see and that they relate to something important."[10]

Many universities have attempted to follow the Stanford model, route 128 in Boston is one example, the North Carolina Research Park is another. All of the successes relate to the association with a research university. However, the research university also must have policies that facilitate technological transfer through close industry-university relationships. The successful universities also have had programs which are strong in engineering, and the engineering professors took the lead of spinning off new high technological firms. Computer science and biomedical professors are also increasingly engaged in entrepreneurial activities. Engineering, computer science and biomedicine are all highly applied university fields. They do not exist as pure academic disciplines. Commercial firms exploit the advantages and basic knowledge that are made by university scholars.[10]

Everett Rodgers and Judith Larsen[10] point out "It is worth noting that Harvard and Berkeley, universities near MIT and Stanford, respectively, did not play much of a role in Route 128 or in Silicon Valley. They are excellent academic institutions, but both Berkeley and Harvard lack an ethos favorable for technology transfer from university scientists to private firms. Neither Berkeley nor Harvard is particularly strong in engineering; their strength is in more basic science and fields like the social sciences and humanities. There were two important spin-offs from Harvard University to Route 128, Wang Laboratories begun in 1952 by Dr. Wang of Harvard's computer lab and Polaroid launched in 1937 by Ed Land. There were almost no Harvard spin-offs during the 60's and 70's when the MIT engineers were busy getting Route 128 going.

California Institute of Technology in Pas-

adena is an outstanding engineering school; it has one special kind of spin-off—the jet propulsion laboratory which does high technology work in aeronautics space industry. But other than JPL, Cal Tech did not help create a high tech complex in Pasadena. "It's as if any entrepreneurial spark that might have been generated at Cal Tech suffocated in the smog of the greater Los Angeles basin,"[10] In an information society the university, particularly the research university, where the production of Ph.D.s and the conduct of scientific research is the main activity of the central institution much as the factory was in the previous area of industrial society, it is not an accident that most high technology systems in the United States are centered around a prestigious research university. A nearby source of well trained graduates for work in high technology firms plus a steady flow of research-based technologies are important contributions by the research university in Silicon Valley.

Since the founding of Stanford in 1951, there have been 18 other specifically related research parks which have been created in attempts to attract industrial firms—all were modeled after Stanford's. The University of Miami has been unable to attract any industrial occupants and the university research park in Georgia has been able to attract only one occupant, the University Nursery School for Faculty Children.[10]

Another very important aspect of all of these is the venture capital. One third of the available capital is concentrated in Silicon Valley, most of the rest is in New York and Boston and almost none of it in other parts of the United States. Other important aspects are the climate and quality of life.[10]

People who can work anywhere generally prefer to reside in an area with a sunny climate. However, sunshine is not the only aspect, the quality of life such as the availability of beaches, ski areas, theatres and other culture amenities which can be found in a metropolitan center also seem to be important for success.

However, it has been suggested the most important single factor is entrepreneurial fever. It's doubtful that a university in formal classes can teach entrepreneurship. Entrepreneurship is probably best learned by example. Successful role models who people can actually meet and get to know lead to the "he did it, why can't I" concept. Most communities and states that attempt to establish a scientific complex seek to do it by transplanting growth and appear to ignore the importance of growth from within. Instead of trying to seduce other cities' companies, officials wanting to start a high tech complex should be thinking about their own spin-offs. The conglomeration of spin-offs in the same neighborhood as their parent firms is why high technology complex builds up in a region. The chain reaction of spin-offs from spin-offs is a kind of natural process. Setting off the initial spark is the key.[10]

The research triangle in North Carolina began in 1960 with the founding of Research Triangle Park which was a 6,000 acre Research and Development center that now contains 40 private government organizations in such fields as electronics, pharmaceuticals, and air pollution. An early boost was provided by IBM when it decided to locate one of its Research and Development operations there in 1965. With the cooperation of Duke, North Carolina State and the University of North Carolina, along with the support of the state government, the research triangle offered low taxes, freedom from unionization and a pleasant climate. The Research Triangle has also generally concentrated on microelectronics and the North Carolina governor has recently convinced his legislature to put up 24 million dollars for a microelectronic center at North Carolina, a research and training facility. However, the Research Triangle does not yet have venture capital, nor has it yet developed the entrepreneurial spin-offs.[10]

Everett Rodgers[10] suggests that the successful high technology complexes have been planned, have a research university with policies to encourage the involvement of faculty with industry, have venture capital present, have the entrepreneurial spirit

demonstrated by spin-offs and have either good climate or quality of life or both. The other aspect is a commitment from the universities, the state governments and a key industry to begin the process. Both Virginia and Maryland, through the state governments and universities, are promoting the concept of developing research parks in the Metropolitan area in Northern Virginia and near the University of Maryland. It is too early to tell whether or not these ventures will be successful. Both have some of the necessary ingredients, but neither has them all. The Virginia General Assemby has approved $11 million for the construction of a center for innovative technology to be built near Dulles International Airport, plus an additional $19 million to improve research facilities at five of the state universities.[11]

The state of Ohio is using fields in which Ohio is already strong to develop its university-high tech center. For example, the Edison Polymer Innovation Corporation received slightly more than five million dollars from the state and will be operated jointly by the University of Akron and Case Western Reserve.[12]

Will higher education meet the challenges of high technology? Higher education can, but only through the cooperation of industry, state and federal government and changing approaches to university policies.

There is probably going to be a need for increasing sponsorship by the government for basic research, more tax incentives for corporate contributions to educational institutions, more flexibility in both universities and corporations in their employment policies and there needs to be strengthening of patent laws. There needs to be establishment of a comprehensive and forward-looking federal policy that recognizes the role of science and technology in the economic health of the country and encourages innovative scientific and technological development facilitating their incorporation into the economy.

As the American Chemical Society communicated recently[13] "We must sustain a strong and long-term federal commitment to the development of a creative scientific personnel in a knowledge base upon which the country can base its economic future."

The universities are the central key in the development of their faculty and their facilities to better train students. It is going to take everyone's effort to ensure success.

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Mathematical Selection of the Optimum Uniform Partition Search

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ABSTRACT

Given a sorted list of records, traditional search algorithms attempt to minimize the number of comparisons. If the list is on magnetic tape or similar media, however, time spent moving the tape becomes significant. In this paper, the author develops a pair of formulae which determine the fastest search algorithm given the characteristics of the data storage device. Applying the results to a typical test case resulted in a 42% reduction in search time over the binary search and a 55% reduction in time over the sequential search.

1. Introduction

Given a sorted list of records, traditional search algorithms attempt to minimize the number of comparisons, or, equivalently, the number of reads into the list. If the list is on magnetic tape or similar media, however, time spent moving the tape becomes significant. Thus, the problem is to minimize search time if we include both time spent reading records and time spent traveling from one record to another.

We shall restrict ourselves to uniform partition searches, i.e. searches which consist of recursively dividing the list into sublists of uniform size. The uniform partition search that partitions each list into two equal sublists is the binary search, designated by p = 2. When p = 3, we partition each list into three equal sublists. When p equals the total number of records, we have a sequential search. Thus, the integer p, between 2 and n, determines a search algorithm ranging from the binary search, when p = 2, to the sequential search, when p = n. We shall use the word "level" to denote partitioning the list (or sublist) into p sublists, i.e. one level of a search with p = 3 entails partitioning the list into three sublists and finding the sublist which contains the desired record; the next level partitions this sublist into three equal (sub)sublists and finding the (sub)sublist which contains the desired record.

2. Derivation

To find the optimum number of partitions, *p*, we must derive a function which returns search time given *p*. Since search

time is the sum of travel time and read time, we have:

$$f(p) = K_r r(p) + K_t t(p) \qquad (1)$$

where

$f(p)$ = the time function
p = the number of partitions per level
$r(p)$ = the number of reads needed during the search
$t(p)$ = the distance (in records) traveled during the search
K_r = time required to read one record
K_t = time required to travel over one record

Let us now consider $r(p)$ and $t(p)$ separately. The number of reads, $r(p)$, is equal to the product of the number of levels and the number of reads per level. Since each level produces a sublist which is $1/p$ the size of the list, searching a list of n records will require $\log_p n$ levels. The probability that the desired record be in any one of the p sublists is $1/p$. It takes one read to discover that the desired record is in the first sublist; two reads, the second sublist; three reads, the third; and so forth. However, if the desired record is in the pth (the last) sublist, we will know after making p-1 reads because the record was not in sublists 1 through p-1. Therefore, the average number of reads is:

$$r(p) = (\log_p n)\left[\frac{1}{p}\right](1 + 2 + 3 + \ldots + p - 2 + p - 1 + p - 1) \qquad (2)$$

$$= (\log_p n)\,\frac{(p + 2)(p - 1)}{2p}$$

The distance traveled on a given level is related to the number of reads per level because, for each read, we must travel over $1/p$ of the list. On the first level, the list is n records long, so $1/p$ of the list is n/p. Therefore, the average distance traveled on the first level is $n(p + 2)(p - 1)/2p^2$. Each successive level will have the same average travel, except that it will be $1/p$ as much. Therefore, the average travel, $t(p)$, is the sum of the geometric series:

$$t(p) = \frac{\left[\dfrac{n(p + 2)(p - 1)}{2p^2}\right]}{1 - \dfrac{1}{p}} = \frac{n(p + 2)}{2p} \qquad (3)$$

Combining equations (1), (2), and (3), we get our function for search time:

$$f(p) = K_r \log_p n\,\frac{(p + 2)(p - 1)}{2p} + K_t\,\frac{n(p + 2)}{2p} \qquad (4)$$

3. Analysis

Before we start general analysis of $f(p)$, let us consider two special cases. First, if we disregard travel time, we should get minimum search time at $p = 2$, i.e. a binary search. Setting $K_t = 0$, we have:

$$f(p) = K_r\,\frac{(p + 2)(p - 1)}{2p \log_n p} \qquad (5)$$

Since the numerator is $0(p^2)$ and the denominator is $0(p \log p)$, we know that p should be small. Numerical calculations show that $p = 2$ is, indeed, optimum.

The second special case occurs when we disregard read time. In this case, $p = n$, i.e. a sequential search, should be optimum. Setting $K_r = 0$, we have:

$$f(p) = K_t\,\frac{n(p + 2)}{2p} \qquad (6)$$

which is monotonically decreasing as p increases. Therefore, p should be as large as possible, giving $p = n$ as optimum.

In general, we differentiate equation (4) and set it equal to zero, yielding:

$$\frac{df}{dp}(p)$$

$$= \frac{K_r \ln n}{2}\left[\frac{p^2 \ln p - p^2 - p + 2 \ln p + 2}{p^2(\ln p)^2}\right] - \frac{K_t n}{p^2} = 0 \quad (7)$$

As n approaches infinity, so will p. Asymptotically, we get:

$$\frac{K_r \ln n}{2 \ln p} - \frac{K_t\, n}{p^2} \quad (8)$$

more beautifully expressed as:

$$\frac{p^2}{\ln p} = \left(\frac{K_t}{K_r}\right)\frac{(\sqrt{n})^2}{\ln \sqrt{n}} \quad (9)$$

which gives us the optimum p given n, K_t, and K_r.

Note the interesting relationship between p and $\sqrt{n}$.

4. Conclusions

We have two equations ((4) and (9)) which can be used to minimize search time. Equation (4) returns search time. By using any of several numerical methods, we can find the optimum p. If n is large and the ratio K_t/K_r is not close to zero, we can use the simpler asymptotic formula, equation (9).

Testing the results of equation (4) on Knuth's MIXT tape unit[1] produced a search time 42% faster than a binary search, 55% faster than a sequential search, and only 0.04% slower than the empirical optimum. Using the p from equation (9) produced identical speed improvement. Thus, these formulae should be eminently useful.

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On Electrodynamic Processes of Electrified Bodies in Motion*

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ABSTRACT

It is shown that there exists a homology of structure between the electrodynamic field equations derived in accordance with non-relativistic concepts set forth by von Helmholtz and Hertz (lacking the Fitzgerald contraction factor), and the similar electrodynamic field equations which are derived by means of the 1-parameter Lorentz tranformation group. Hertz's generalized version of Faraday's law which he expressed as 3 scalar equations, is re-developed here in vectorial format. Although the vector equation expressing Hertz's 3 generalized scalar equations of the Ampère's law was derived, it is not included, since the same method is used. These equations are constructed with the symmetrized electric and magnetic 6 field equivalence relations that relate a field in motion relative to an observer, to one at rest, and which relations were respectively derived by Helmholtz in 1874 and Hertz in 1890, and which resemble the 6 similar expressions that are extracted from the Maxwell field equations after transformation by the Lorentz group, in the special relativity theory. These 6 self-same relations were introduced by Hertz into his re-formulation of the Maxwell equations in order to extend them to electrodynamics.

Mention is also made of the work of G. F. C. Searle in 1896 and O. Heaviside in 1881, to indicate that researches had already been initiated towards a second order theory (i.e., v^2/c^2) in electrodynamics at that time. And mention is also made of B. Riemann's suggestion of 1861, to show that he had a proto-recognition of the need for a theory to describe a second order electrodynamics, which would go beyond the Weber-Fechner theory, before Maxwell's theory appeared.

§1. Introduction

The recent publication by my friend and long time colleague Thomas Phipps [1], of his demonstration of the form-invariance of the Maxwell-von Helmholtz-Hertz electromagnetic field equations [2a, 2b; 3] under the group G_∞ of Galilean transformations, has led me to consider re-emphasizing and extending my 1967 published observations that the Hertzian formulation of the Maxwell electromagnetic field equations for bodies at rest, can be reformulated by means of 1874 electric force constructions due to von Helmholtz, in addition to

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1890 magnetic force constructions due to Hertz, in such a way, as will be shown in §3, that the resulting field equations are completely homologous in structure to those arrived at by H. A. Lorentz in 1904 and by Albert Einstein in 1905 for bodies in motion. This result from historical perspective, is conjoined by Phipps's demonstration of form-invariance of the Hertzian formulation of the electromagnetic field equations, when transformed under the group G_∞ of Galilean transformations.

At the time when I published my brief note [4] in January of 1967, I was enamored by the fact that I could express Hertz's generalized equations 1_a and 1_b for the electromagnetics of bodies in motion

Faraday's law of induction

(1_a) $\partial_t H + \nabla \times (H \times V) + V \nabla \cdot H = c \nabla \times E$
with
$\nabla \times (H \times V) = V \cdot \nabla H - H \cdot \nabla V + H \nabla \cdot V - V \nabla \cdot H$

Ampère's law

(1_b) $\partial_t E + \nabla \times (E \times V) + V \nabla \cdot E = -c \nabla \times H - 4\pi J$
with
$\nabla \times (E \times V) = V \cdot \nabla E - E \cdot \nabla V + E \nabla \cdot V - V \nabla \cdot E$,
c being the velocity of the propagation of light in vacuo,
J being the electric current-density vector.

in the following format, after having made suitable physical restrictions:

$$\partial_{ct} L = \partial_y\left(Z + \frac{v}{c} M\right) - \partial_z\left(Y - \frac{v}{c} N\right)$$

$$\partial_{ct} M = -\partial_x\left(Z + \frac{v}{c} M\right) + \partial_z X$$

$$\partial_{ct} N = \partial_x\left(Y - \frac{v}{c} N\right) - \partial_y X$$

$$\partial_{ct} X = -\partial_y\left(N - \frac{v}{c} Y\right) + \partial_z\left(M + \frac{v}{c} Z\right)$$

$$\partial_{ct} Y = \partial_x\left(N - \frac{v}{c} Y\right) - \partial_z L$$

$$\partial_{ct} Z = -\partial_x\left(M + \frac{v}{c} Z\right) + \partial_y L$$

But the above reformulations of Hertz's anti-symmetric fundamental equations 1_a and 1_b, expressing Faraday's and Ampère's laws, lack the Fitzgerald contraction factor. It can be seen that there exists a homologous correspondence between Hertz's electrodynamic fundamental equations for electrified bodies in motion, to those covariantly transformed by means of the Lorentz transformation group. Hertz's electrodynamic equations were constructed from the Maxwell equations for electrified bodies at rest, with the symmetrized electric and magnetic 6 field equivalence relations. These field equivalence relations relate a field in motion relative to an observer at rest, to a field at rest in the observer's rest frame. These relations were respectively derived by Helmholtz in 1874 and Hertz in 1890. They resemble the 6 similar expressions (each with a Fitzgerald contraction factor attached as a reciprocal) that are extracted from the Maxwell field equations after transformation by the Lorentz group.

No conclusion will be drawn here concerning the Einstein reciprocity interpretation that is implied from the kinematic symmetry of reciprocal observers, who are in relative motion with respect to each other. Their respective coordinate systems are related by the group of Lorentz transformations.

Considerations involving the formulation of the Maxwell electromagnetic equations and the selection of units, as was discussed by Leigh Page [5] in 1933, may be applied to the study of the Hertzian equations. But the homology of the structures derived by Helmholtz and Hertz, to the similarly structured field forces for electrified bodies in motion that are derived under the Lorentz group, is independent of the selection of units.

"The English still adhere to the electrostatic and the electromagnetic units of Maxwell and the two corresponding sets of asymmetrical equations, whereas in Eu-

rope and to a considerable extent in this country the symmetrical Heaviside-Lorentz or the Gaussian equations are employed."

§2. *The work of Phipps concerning the demonstration of form-invariance of the Hertzian formulation of the electromagnetic field equations* (*An elementary method of demonstration of form-invariance*). Let us examine for example, the reduced form (since V is constant) of the single curl equation (consisting of 3 scalar equations) which expresses Faraday's law of induction, to wit,

$$\partial_t H + V \cdot \nabla H = c\nabla \times E.$$

This equation can be form-invariantly transformed under the group G_∞ of Galilean coordinate transformations, so that this system of equations with reference to the coordinate system (x, y, z, t) can now be expressed with reference to the coordinate system (ξ, η, ζ, τ) in uniform translatory motion with velocity v relative to (x, y, z, t).

The velocity relation $V' = V - v$ (for the particular case of motion along the x-axis in this example) can be derived from the coordinate transformation $\xi = x - vt$ by differentiation by t, where $\partial_t\xi = V'$, $\partial_t x = V$, and $\tau = t$.

Examine the single equation[1]

$$Z_y - Y_z = -L_{ct} - VL_{cx}.$$

By substitution of the partials derived by means of the chain rule

$$Z_y = Z_\xi \xi_y + Z_\eta \eta_y + Z_\zeta \zeta_y + Z_\tau \tau_y \text{ etc.}$$

with respect to the Galilean coordinate transformations

$$\xi = x - vt, \eta = y, \zeta = z, \tau = t$$

and further substitution of the velocity parameter relation $V' = V - v$, one gets the transformed scalar equation

$$Z_\eta - Y_\zeta = -L_{c_\tau} - V' L_{c_\xi}.$$

The same kind of demonstration can easily be shown in the case of Ampère's law in the absence of conduction and convection currents.

ADDENDUM. *Further remarks about form-invariance.* With regard to form-invariance of the Hertzian equations, Hertz [2b; pp. 246–7] wrote the following in 1890, about his system of equations.

"Our method of deducing the equations . . . does not require that the system of co-ordinates used should remain absolutely fixed in space. We can, therefore, without change of form, transform our equations from the system of co-ordinates moving in any manner through space, by taking α, β, γ to represent the velocity-components with reference to the new system of co-ordinates, and referring the constants ϵ, μ, λ, X', Y', Z', which depend upon direction, at every instant to these. From this it follows that the absolute motion of a rigid system of bodies has no effect upon any internal electromagnetic processes whatever in it, provided that all the bodies under consideration, including the ether as well, actually share the motion. It further follows from this consideration that even if only a single part of a moving system moves as a rigid body, the processes which occur in this part follow exactly the same course as in bodies at rest. If, nevertheless, the existing motion does exert any influence upon this part, this influence can only arise in those portions of the system in which distortion of the elements occurs, and must be propagated thence into those portions which move after the manner of rigid bodies."

§3. *Derivation of a format of the Hertzian electromagnetic field equations which is completely homologous to the format of the Maxwell field equations transformed under the group of Lorentz transformations.* Hertz's formulation of the Maxwell field equations for bodies at rest is

$$\partial_{ct}L = \partial_y Z - \partial_z Y \qquad \partial_{ct}X = \partial_z M - \partial_y N$$
$$\partial_{ct}M = \partial_z X - \partial_x Z \qquad \partial_{ct}Y = \partial_x N - \partial_z L$$
$$\partial_{ct}N = \partial_x Y - \partial_y X \qquad \partial_{ct}Z = \partial_y L - \partial_x M$$

von Helmholtz [3] first showed in 1874, using the older action-at-a-distance theories

[1] Use is made here of the sub-script notation as applied by R. Courant. See his *Differential and Integral Calculus*, vol. II, Interscience Publ. Inc., New York, 1956 edn., p. 142.

of Franz Neumann and W. Weber [6], that if the electrostatic and magnetic forces are placed in opposition to the electromagnetic forces, then new relations could be derived which express the orthogonal components $X, Y, Z,$ of electric force arising as soon as a body moves in a magnetic field. Hertz developed a second set of such relations in 1890 which express the orthogonal components $L, M, N,$ of magnetic force experienced in a non-conductor displaced through lines of force of an electric field. Under suitable physical and kinematical restrictions, the following occurs where $A = 1/c$.

von Helmholtz 1874

$$\left.\begin{aligned} X_1 &= A(\gamma M - \beta N) \\ Y_1 &= A(\alpha N - \gamma L) \\ Z_1 &= A(\beta L - \alpha M) \end{aligned}\right\} \rightarrow \begin{aligned} &0 \\ &\frac{v}{c} N \\ -&\frac{v}{c} M \end{aligned}$$

Hertz 1890

$$\left.\begin{aligned} L_1 &= A(\beta Z - \gamma Y) \\ M_1 &= A(\gamma X - \alpha Z) \\ N_1 &= A(\alpha Y - \beta X) \end{aligned}\right\} \rightarrow \begin{aligned} &0 \\ -&\frac{v}{c} Z \\ &\frac{v}{c} N \end{aligned}$$

X, Y, Z are orthogonal components of electric polarization (of the ether)
L, M, N are orthogonal components of magnetic polarization (of the ether)

As Hertz has done, we split the forces so that

$$\begin{aligned} X &= X_1 + X_2 & L &= L_1 + L_2 \\ Y &= Y_1 + Y_2 & M &= M_1 + M_2 \\ Z &= Z_1 + Z_2 & N &= N_1 + N_2 \end{aligned}$$

where L_2, M_2, N_2 are the magnetic orthogonal components and X_2, Y_2, Z_2 are the electric force orthogonal components of the system in translational motion with velocity v, with respect to the rest frame of the observer. The orthogonal electric field components $X, Y, Z,$ and the orthogonal magnetic field components $L, M, N,$ are those field components of a system at rest relative to the observer.

In this conceptualization within the framework of the Galilean transformation, this motion describes a slowly moving electron in the microcase for example, and is an approximation to the relativistic case. This conceptualization is capable of being formulated as either a 3- or 4-dimensional picture, in which latter case it depends on the explicit usage of the homogeneous holonomic coordinates x, y, z, ct for a consistent representation. The usage of the operator ∂_{ct} on L_2 etc. instead of $(1/c \times \partial/\partial t)$ on L_2 etc. stresses the 4-dimensional picture, whereas the latter lays stress upon the 3-dimensional picture. The advantage of using the 4-dimensional picture, it turns out, is that as an added bonus, one is able to construct the two anti-symmetric 2nd order cartesian World tensors[2]

$$\begin{Bmatrix} 0 & Z_2 & -Y_2 & -L_2 \\ -Z_2 & 0 & X_2 & -M_2 \\ Y_2 & -X_2 & 0 & -N_2 \\ L_2 & M_2 & N_2 & 0 \end{Bmatrix}$$

and

$$\begin{Bmatrix} 0 & -N_2 & M_2 & -X_2 \\ N_2 & 0 & -L_2 & -Y_2 \\ -M_2 & L_2 & 0 & -Z_2 \\ X_2 & Y_2 & Z_2 & 0 \end{Bmatrix}$$

Because of the property of distributivity of differential operators, and by taking differences, i.e.

$$\partial_{ct} M = \partial_{ct}(M_1 + M_2) = \partial_{ct} M_1 + \partial_{ct} M_2 \rightarrow$$
$$\partial_{ct} M_2 = \partial_{ct} M - \partial_{ct} M_1$$

etc., the original formulation of the electro-

[2] It is possible to use the operator format $(1/c \times \partial/\partial t)$ to express a second version of both of the above 4-dimensional cartesian World tensors, but in this case one gives up the application of homogeneous coordinates. Both formulations of the field equations in these 2 format cases however, use the Gaussian system of mixed units, i.e., e.m.u. and e.s.u. Handedness of the system of field equations must be taken into account for a complete sign correspondence of tensor components.

magnetic field equations, can now be reformulated as

$$\begin{aligned}
\partial_{ct}L_2 &= \partial_y Z_2 - \partial_z Y_2 \\
\partial_{ct}M_2 &= \partial_z X_2 - \partial_x Z_2 \\
\partial_{ct}N_2 &= \partial_x Y_2 - \partial_y X_2 \\
\partial_{ct}X_2 &= \partial_z M_2 - \partial_y N_2 \\
\partial_{ct}Y_2 &= \partial_x N_2 - \partial_z L_2 \\
\partial_{ct}Z_2 &= \partial_y L_2 - \partial_x M_2
\end{aligned}$$

where

$$\begin{aligned}
X_2 &= X & L_2 &= L \\
Y_2 &= Y - \frac{v}{c} N & M_2 &= M + \frac{v}{c} Z \\
Z_2 &= Z + \frac{v}{c} M & N_2 &= N - \frac{v}{c} Y
\end{aligned}$$

which provides an equation structure that is completely homologous to that arrived at by H. A. Lorentz in 1904 and Albert Einstein in 1905.

NOTE. If one changes the sense of the coordinate system from a right handed one to a left handed one, those terms on only one side of the Maxwell equations merely change sign. Maxwell used a different handedness from von Helmholtz, who used the other handedness.

§4. *Historical note.* G. F. C. Searle [7] had in 1896, by the use of different methods, developed the same expressions as the ones above. Thus he had:

$$\begin{aligned}
&X & &L \\
&Y - \frac{v}{c} N & &M + \frac{v}{c} Z \\
&Z + \frac{v}{c} M & &N - \frac{v}{c} Y
\end{aligned}$$

The term $c^2/(c^2 - v^2) = (1 - v^2/c^2)^{-1}$ was found by Oliver Heaviside in 1881. Hertz acknowledged that Oliver Heaviside, working in the same vein as himself, had since 1885 begun to simplify and extract the essence of the Maxwell field equations.

It may be of interest to review K. Hattendorf, "*Schwere, Elektricität und Magnetismus nach den Vorlesungen von B. Riemann*" (Hannover, 1875) p. 326, for a description of Riemann's 1861 suggestion concerning the presentation by Weber of his electrokinetic energy formulation. Refer to footnote 2 on p. 206, of E. Whittaker, "*A History of the Theories of Aether and Electricity*", vol. 1, Harper & Brothers, New York, 1960, for the Lagrangian function of Riemann's electrokinetic theory of 1861. Note the Fitzgerald contraction factor.

Acknowledgments

My thanks go to Tom Phipps for his encouragement and warmth, and his steadfast position regarding the application of the Galilean transformation to Hertz's electrodynamic equations. And my thanks go also to my long time friend Morton Lutzky (of the Naval Surface Weapons Center) for his helpful crystallizing discussion on the essentials of the Galilean transformation, and the dependency of the velocity relation on the coordinate transformations. I suppose that as a first case, Woldemar Voigt would have immediately written the transformations as

$$\xi = x - lvt, \eta = y - mvt, \zeta = z - nvt, \tau = t$$

with $l^2 + m^2 + n^2 = 1$, forming a group with 3 essential parameters; v and 2 direction cosines.

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APPENDIX. *Derivation of the vector format of Hertz's version of Faraday's law.* Hertz expressed his 1890 extension of Faraday's law as

$$A\{\partial_t L + \partial_y(\beta L - \alpha M) - \partial_z(\alpha N - \gamma L) + \alpha B\} = \partial_y Z - \partial_z Y$$

$$A\{\partial_t M\ \partial_x(\beta L - \alpha M) + \partial_z(\gamma M - \beta N) + \beta B\} = -\partial_x Z + \partial_z X$$

$$A\{\partial_t N + \partial_x(\alpha N - \gamma L) - \partial_y(\gamma M - \beta N) + \gamma B\} = \partial_x Y - \partial_y X$$

where with respect to the x-, y-, and z-coordinate axes,

L, M, N are the orthogonal components of magnetic polarization
$\alpha = V_x$, $\beta = V_y$, and $\gamma = V_z$ are the velocity components of the electrified body in uniform motion
X, Y, Z are the orthogonal components of the electric force vector E
$B = \partial_x L + \partial_y M + \partial_z N = \nabla \cdot \boldsymbol{H}$
$A = 1/c$ where c is the velocity of the propagation of light in vacuo

These equations to which Hertz referred as 1_a in his paper [2b], can now be re-expressed as

where

$$F_{12} = V_y L - V_x M, \qquad F_{13} = V_x N - V_z L, \qquad F_{23} = V_z M - V_y n$$

and

$$if_1 = i(\partial_y F_{12} - \partial_z F_{13}),$$
$$jf_2 = j(\partial_z F_{23} - \partial_x F_{12}),$$
$$kf_3 = k(\partial_x F_{13} - \partial_y F_{23})$$

Derivation of the curl, $\nabla \times (\boldsymbol{H} \times V)$.

$$if_1 + jf_2 + kf_3 = i\partial_y F_{12} - i\partial_z F_{13} + -j\partial_x F_{12} + j\partial_z F_{23} + k\partial_x F_{13} - k\partial_y F_{23}$$

By distributing with respect to F_{ij} ($i, j = 1, 2, 3$) one gets

$$\begin{aligned}
&(i\partial_y - j\partial_x)F_{12} + (k\partial_x - i\partial_z)F_{13} \\
&\quad + (j\partial_z - k\partial_y)F_{23} = (j \times k\partial_y - k \times i\partial_x)F_{12} \\
&\quad + (i \times j\partial_x - j \times k\partial_z)F_{13} \\
&\quad + (k \times i\partial_z - i \times j\partial_y)F_{23} \\
&\quad = (j \times k\partial_y + i \times k\partial_x)F_{12} \\
&\quad + (i \times j\partial_x + k \times j\partial_z)F_{13} \\
&\quad + (k \times i\partial_z + j \times i\partial_y)F_{23} \\
&\quad = (j\partial_y + i\partial_x) \times kF_{12} \\
&\quad + (i\partial_x + k\partial_z) \times jF_{13} \\
&\quad + (k\partial_z + j\partial_y) \times iF_{23} \\
&\quad = (i\partial_x + j\partial_y + k\partial_z) \times kF_{12} \\
&\quad + (i\partial_x + j\partial_y + k\partial_z) \times jF_{13} \\
&\quad + (i\partial_x + j\partial_y + k\partial_z) \times iF_{23} \\
&\quad = \nabla \times (iF_{23} + jF_{13} + kF_{12}) \\
&\quad = \nabla \times [(V_z M - V_y n)i + (V_x N - V_z L)j \\
&\quad + (V_y L - V_x M)k] = \nabla \times [(Li + Mj + Nk) \\
&\qquad \times (V_x i + V_y j + V_z k)] = \nabla \times (\boldsymbol{H} \times V)
\end{aligned}$$

$$\left.\begin{array}{l|l|l}
i\partial_t L & + i\partial_y F_{12} - i\partial_z F_{13} & + iV_x\partial_x L + iV_x\partial_y M + iV_x\partial_z N \\
+ & \qquad\qquad + & \quad + \qquad + \qquad + \\
j\partial_t M & - j\partial_x F_{12} \qquad + j\partial_z F_{23} & + jV_y\partial_x L + jV_y\partial_y M + jV_y\partial_z N \\
+ & + \qquad + & \quad + \qquad + \qquad + \\
k\partial_t N & + k\partial_x F_{13} - k\partial_y F_{23} & + kV_z\partial_x L + kV_z\partial_y M + kV_z\partial_z N
\end{array}\right\} = \left\{\begin{array}{l}
ic(\partial_y Z - \partial_z Y) \\
\\
jc(\partial_z X - \partial_x Z) \\
\\
kc(\partial_x Y - \partial_y X)
\end{array}\right.$$

$$\partial_t \boldsymbol{H} \quad + if_1 + jf_2 + kf_3 \quad + \underbrace{V\partial_x L + V\partial_y M + V\partial_z N}_{V\nabla\cdot\boldsymbol{H}} \quad = \quad c\nabla \times E$$

Notice that the above construction of the operator ∇ is made by adding the terms $i \times i = j \times j = k \times k = 0$.

Three depictions of Hertz's representation of Faraday's law. Therefore, from the above reformulation, Hertz's extension of Faraday's law can be expressed as

$$\partial_t \boldsymbol{H} + \nabla \times (\boldsymbol{H} \times V) + V\nabla \cdot \boldsymbol{H} = c\nabla \times E \quad \text{eqn. A}$$

However,

$$rot(\boldsymbol{H} \times V) = \nabla \times (\boldsymbol{H} \times V) = V \cdot \nabla \boldsymbol{H} - (\nabla \cdot \boldsymbol{H})V + (\nabla \cdot V)\boldsymbol{H} - \boldsymbol{H} \cdot \nabla V$$

and therefore, the equation of the law can now be expressed as

$$\partial_t \boldsymbol{H} + V \cdot \nabla \boldsymbol{H} = c\nabla \times E \quad \text{eqn. B}$$

since ∇V and $\nabla \cdot V$ vanish because V is uniform and therefore unchanging.

By means of suitable restriction, the components of magnetic polarization can be reduced to the orthogonal components L, M, N of the magnetic force vector H. This can be accomplished if the second order contravariant permeability tensor is such that $\mu^{ij} = \delta^{ij}$, where the contravariant Kronecker delta

$$\delta^{ij} = \begin{cases} 0 \text{ if } i \neq j \\ 1 \text{ if } i = j \end{cases}$$

When this restriction is made, one can then rewrite the vector equation as

$$\partial_t H + V \cdot \nabla H = c\nabla \times E \quad \text{eqn. C}$$

where H is the magnetic force vector.

Ampère's law. The vector format for Ampère's law may be derived in a similar manner; and I have shown this as equation 1_b of the Introduction. The vectorial derivation of Ampère's law is omitted here in order to save printing space. The above example should suffice.

Historical remarks regarding Hertz's use of the partial derivative. The notation for the partial differential coefficient that was used by Hertz, was *d/dx* etc. This use of the "straight-backed *d*" was in common usage during the 19th century, and its meaning as a partial was intended to be conveyed from its context. This same notation, for example, was also used by H. von Helmholtz, J. C. Maxwell, O. Heaviside, and G. F. C. Searle; authors, whose work in the study of electromagnetics has been referred to above. This failure to adopt the "curly-*d*" for partial differentiation (which was independently rediscovered in 1841 by C. G. J. Jacobi, although it was first used in 1770 by the Marquis de Condorcet[1], and a little later by A. M. Legendre[1] in 1786) is highlighted by the remark made by S. F. Lacroix[2] in 1810, viz.,

"Really, *dz/dx*, *dz/dy* are as clear as (*dz/dx*), (*dz/dy*) when one knows beforehand that *z* is a function of two independent variables *x* and *y*, which the statement of the question, or the meaning of which it is susceptible, always indicates".[3]

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[1] See p. 225 of *"A history of mathematical notations"*, vol. 2, by F. Cajori, The Open Court Publishing Company, Chicago, Illinois.

[2] Ibidem, pp. 226–7.

[3] The above cited notation which parenthetisizes the "straight *d*", is due to L. Euler, and he first used it in the year 1755.

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The Scientific Achievement Awards of the Academy: 1984

Sherman Ross

General Chairman, Washington Academy of Sciences

The Scientific Achievement Awards of the Academy were presented at a meeting on March 28, 1984 at The American University, Washington, D.C. Nine awards were made for significant contributions to research, and one award for science teaching. This program of the Academy was started in 1939 to recognize young scientists for ". . . noteworthy discovery, accomplishment, or publication in the Biological, Physical, and Engineering Sciences." An award for Outstanding Teaching was added in 1955 (renamed in 1979 as the Leo Schubert Award), and in Mathematics in 1959. In 1975 the award for the Behavioral Sciences was added, as well as the Berenice G. Lambert Award for Teaching of High School Science.

Awards for Scientific Achievement were presented to the following individuals for distinguished contributions:

Robert J. Englar, (David W. Taylor Naval Ship Research and Development Center, Bethesda, MD) was selected in the Engineering Sciences for outstanding achievements in high lift wing system development. Throughout his career, starting in 1965 as a co-op student, Mr. Englar has demonstrated an unusual understanding of engineering principles and an exceptional ability in applying these principles to problem solving in aerodynamic research. In particular he developed a naval high lift wing concept, the Circulation Control Wing (CCW). The application can revolutionize aircraft wing designs and structures so that they no longer have to be compromised by the complexities of low speed mechanical high lift systems, and can be optimized as smaller wings for high speed cruise. His reports, papers, and patents indicate the availability of a revolutionary improvement in simplified aircraft high lift systems, and have provided a major data base for many types of airfoil/hydrofoil/control surface applications.

Mr. Englar received a B.S. degree in Aerospace Engineering from the Virginia Polytechnic Institute, and an M.S. degree in the same area from the University of Maryland. He has had additional study in advanced technology and management.

Gordon C. Everstine, (David Taylor Ship Research & Development Center, Bethesda, MD) was recognized in the area of Mathematical and Computer Sciences for advances in finite element techniques for mechanical problems. He has made significant contributions by developing effective predictive methods for a variety of prob-

lems. The key to the solution of these problems with existing general purpose of finite element structural analysis computer codes was his detailed development of the analogies between the equations of elasticity and those of classical mathematical physics. This work led to Dr. Everstine's development of the first generally available procedure for the reliable prediction of the linear response of general submerged structures to shock loadings. A second major finite element contribution was the development of a computer algorithm and program (BANDIT) to speed up the solution of matrix equations. This contribution has been widely recognized.

Dr. Everstine received a B.S. in Engineering Mechanics from Lehigh University, an M.S. in Engineering from Purdue University, and a Ph.D. in Applied Mathematics from Brown University. He has served at the DTHSRDC since 1969.

Henry W. Heikkinen (University of Maryland) was selected for the Leo Schubert Award for the Teaching of Science for his outstanding teaching/advising in the Department of Chemistry. He has been honored for teaching excellence, and has made extensive contributions in the development and improvement of textbooks, audiovisual materials and microcomputer software for student use. He is recognized nationally and internationally for his activities in chemical education.

Dr. Heikkinen received a B.Eng. in Chemical Engineering from Yale University. He was awarded an M.A. in Science Education from Columbia University, and Ph.D. in Chemical Education from the University of Maryland.

Thomas J. Kelly, (U.S. Department of Agriculture, Beltsville, MD) was recognized in the Biological Sciences for innovative and significant research in insect endocrinology. In the area of insect reproduction and development he has discovered a new larva molding hormone, a new mode of action for an antigonadotropic hormone in Diptera and possibly in other insects and anthropods. In addition, Dr. Kelly has developed a number of highly sensitive assays for quantifying insect hormones, and has investigated their endocrinological roles and interactions.

Dr. Kelly received a B.S. in Chemistry and a Ph.D. in Cell Biology from the University of Illinois at Champaign-Urbana. He did postdoctoral research at the University of Pennsylvania and the University of Notre Dame. Then, he joined the Insect Reproduction Laboratory at the USDA-ARS, Beltsville, MD.

Raja Parasuraman, (The Catholic University of America) was selected in the Behavioral Sciences for his outstanding contributions in the area of vigilance and signal detection. These researches in neuroscience are recognized as innovative and exciting. His studies involve attention, search, monitoring, perception, performance, signal detection, vigilance, and brain correlates (evoked potentials).

Dr. Parasuraman received a B.Sc. degree in Electrical Engineering from the Imperial College of Science and Technology, University of London, and an M.Sc. and Ph.D. in Applied Psychology from the University of Aston, Birmingham, England. After appointments at the Lanchester Polytechnic and the Wolverton Polytechnic in England, he was a research fellow, in the Department of Psychology at U.C.L.A. He came to The Catholic University of America in 1982 as Associate Professor of Psychology and Director of the Psychophysiology Laboratory.

Dr. Phil Skolnick (National Institute of Arthritis, Diabetes, Digestive and Kidney Diseases, Bethesda, MD) was recognized in the Biological Sciences for his contributions toward the characterization of the neurochemical basis of anxiety. In 1978 Dr. Skolnick and his collaborators isolated, characterized and identified the first endogenous ligands of the benzodiazepine receptor and demonstrated behaviorally and electrophysiologically that high concentrations of these agents have high Diazepam-like properties. They showed that the binding of Diazepam to specific receptors occurred *in vivo* and *in vitro.* Further extensive research has yielded a stochastic model of the benzodiazepine receptor. This theo-

retical model may also be applicable to other neurotransmitter systems. In 1982, Dr. Skolnick and his collaborators described the first reproducible, chemically induced model of anxiety in primates.

Dr. Skolnick received a B.S. degree *summa cum laude* from Long Island University, and a Ph.D. in Pharmacology from The George Washington University. He joined the NIAMDD in 1972, and is the current Chief, Section of Neurobiology.

Robert A. Owens, (Beltsville Agriculture Research Center, Beltsville, MD) was honored in the Biological Sciences for his outstanding contributions to viroid molecular biology structure, function, and detection in plants. His efforts have centered about the applications of viroid complementary DNAs to investigations of viroid structure and function. Complementary DNAs have been used to study the molecular mechanisms of viroid replication and to develop a new method for viroid disease diagnosis. The demonstration that these cloned complementary DNAs are infectious permits the mechanisms of viroid replication, symptom, induction and host susceptibility/resistance to be studied by new approaches.

Dr. Owens received a B.S. degree in Botany from the University of Rhode Island, and a Ph.D. degree in Biochemistry and Biophysics from the University of California at Davis. He was a postdoctoral research associate in the Department of Biological Sciences, Columbia University, and then joined the Plant Virology Laboratory as a research chemist.

Hubert Überall, (The Catholic University of America) was recognized for his distinguished contributions to the Physical Sciences for exploring resonances through a wide range of physical phenomena. While originally a theoretical nuclear physicist, Dr. Überall has directed his attention to classical physics, particularly acoustics (underwater acoustics), elastic wave propagation (nondestructive testing), and electromagnetic waves (radar). His work has been recognized widely, and continues.

Dr. Überall received Ph.D. degrees in Physics from the University of Vienna and Cornell University. He was a research fellow at the University of Liverpool, a Ford Foundation Fellow at CERN in Geneva, and a research physicist at the Carnegie Institute of Technology. He served as Assistant Professor of Physics at the University of Michigan before coming to The Catholic University of America in 1964.

John Weiner, (University of Maryland at College Park, MD) was selected in the Physical Sciences for his major contributions in the use of pulsed, tunable radiation fields to control the outcome of molecular collisions. Dr. Weiner studies the effects of intense laser fields on the formation of the products of reacting gaseous molecules. The reaction products are detected by mass spectrometry and photon and electron spectroscopy. The intense electromagnetic field of the laser beam alters the electronic states of the collision intermediates, which then alter the reaction products.

Dr. Weiner received a B.S. degree in Chemistry from the Pennsylvania State University, and a Ph.D. from the University of Chicago. He was a postdoctoral fellow and Lecturer at Yale University, and Assistant Professor at Dartmouth College. He was a Visiting Professor at the University of Paris-Sud. He has been at the University of Maryland since 1978.

Charles L. Wilson, (Appalachian Fruit Research Station, Kearneysville, WV) was selected in the Biological Sciences for his pioneering research in understanding and manipulating plant diseases. Dr. Wilson has carried out research leading to more fundamental understanding of host-parasite interactions in plant diseases, and the biological control of weeds with plant pathogens. He has made major contributions to the understanding of mycoplasma diseases of trees, organible behavior in fungal cells, biological control of plant pathogens, and strategies for dealing with exotic pest introductions.

Dr. Wilson received a B.A. degree in Botany, M.S. and Ph.D. degrees in Plant Pathology and Entomology—all from West Virginia University. He joined the Agricultural Research Service in 1968, and his

work in plant pathology has been widely recognized.

Acknowledgments

The contributions of the chairmen of the various panels and their colleagues, who carried out the difficult task of making the selections, are acknowledged with sincere thanks. The chairmen were: Dr. James H. Howard, Jr. (The Catholic University of America)—Behavioral Sciences; Dr. C. R. Creveling (NIADDK, NIH)—Biological Sciences; Dr. John D. Anderson, Jr. (University of Maryland at College Park)—Engineering Sciences; Dr. Joan Rosenblatt—(National Bureau of Standards)—Mathematical & Computer Sciences; Dr. Mary H. Aldridge (The American University)—Physical Sciences; and Dr. Joseph B. Morris (Howard University)—Teaching of Science.

Thanks are due to the nominators and to the sponsors of all the candidates. On behalf of the Academy we commend the recipients, whose work is honored, and we wish them continued productive careers.

Department of Psychology
Howard University
Washington, D.C. 20059

Journal of The Washington Academy of Sciences,
Volume 74, Number 3, Pages 81–82, September 1984

1984 Elected Fellows of the Academy

John O'Hare

President Elect, Washington Academy of Sciences

The following 17 individuals have been elected as Fellows of the Academy during 1984:

Behavioral Sciences

Dr. Randall M. Chambers
USA Research Institute for the Behavioral and Social Sciences
Alexandria, VA 22333

In recognition of his research contributions and publications in experimental psychology and the aeronautical life sciences; in particular for his original research on (a) performance capabilities of pilots and astronauts during centrifuge-computer simulations of launch, abort and re-entry; (b) effects of high *G* forces on physiological and life-support systems; (c) human factors and performance during air and ground simulations of complex tactical maneuvers; and (d) effects of unusual environmental stress on human behavior.

Mr. Edward M. Connelly
Performance Measurement Associates, Inc.
Vienna, VA 22180

In recognition of his contributions to mathematical modeling of user-machine interactions and, in particular, for his performance models for the aircraft pilot, the ship navigator, and the computer programmer.

Biological Sciences

Dr. John R. Pancella
Montgomery County Public Schools
Rockville, MD 20850

In recognition of his contributions to science education.

Chemistry

Dr. Gordon K. Riel
Naval Surface Weapons Center
White Oak, MD 20910

In recognition of his (a) original measurements of gamma-ray spectra in the ocean; (b) methods for analysis at very low concentrations of radioisotopes; (c) measurements of neutron spectra at very low dose-rates; and (d) technique for correction of energy-dependent neutron dosimeter.

Earth & Space Sciences

Mr. Paul C. Etter
ODSI Defense Systems, Inc.
Rockville, MD 20852

In recognition of his contributions to oceanic research and, in particular, for his work on heat-storage mechanisms in the Gulf of Mexico.

Engineering Sciences

Dr. James E. Baker
AF Office of Scientific Research
Bolling AFB, DC 20332

In recognition of his contributions to automatic speech recognition and his management of Air Force research and development.

Health Sciences

Dr. Walter E. Boek
National Graduate University
Arlington, VA 22201

In recognition of his pioneering and well-recognized research in public health, unmet medical needs, community development, and ethnic relationships in the USA and Canada.

Dr. Louis, D. Bourgeois
8701 Broadmoor Drive
Bethesda, MD 20817

In recognition of laboratory research and improvement of clinical procedures in the field of microbiology.

Dr. Marie J. Bourgeois
8701 Bradmoor Drive
Bethesda, MD 20817

In recognition of significant contributions to the fields of anthropology, public health, and nursing.

Dr. Stanley E. Edinger
HCFA/HSQB/OSC
Baltimore, MD 21207

In recognition of his contributions to research on the chemistry of gypsum, clinical accreditation and training, and health-care standardization.

Dr. George J. Galasso
NIH-NIAID
Bethesda, MD 20205

In recognition of his significant contributions to public health and science through his scientific and administrative skills leading to the advancement and acceptance of antiviral drugs and vaccines.

Dr. Paul L. Kornblith
National Institutes of Health
Bethesda, MD 20205

In recognition of his contributions stemming from his clinical and laboratory studies of human immunology and neoplasms.

Dr. Paul E. Tyler
Naval Medical R & D Command
Bethesda, MD 20814

In recognition of his work in physiology and, in particular, on the effects of cold exposure.

Dr. Thomas A. Waldmann
NIH-National Cancer Institute
Bethesda, MD 20205

In recognition of his significant contributions to the understanding of the regulation of the normal immune system and the disorders in these immunoregulatory mechanisms that underlie human diseases.

Mathematics

Dr. Stefan Shrier
CTEC. Inc.
McLean, VA 22101

In recognition of his contributions to applied mathematics and, in particular, his research on machine intelligence, applied logic and computer science.

Physics

Dr. Bhakta B. Rath
Naval Research Laboratory
Code 6300
Washington, DC 20375

In recognition of his many and varied contributions to advancing the field of physical metallurgy and, in particular, his research on transformations, recrystallization and texture of metals and alloys.

Dr. Victor J. Sank
National Institutes of Health
Bethesda, MD 20205

In recognition of his contributions to medical imaging and, in particular, to the design and construction of a high-resolution, high-sensitivity positron emission tomographic scanner.

Journal of The Washington Academy of Sciences,
Volume 74, Number 3, Page 83, September 1984.

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Page 2 should contain an abstract which should be intelligible without reference to the text of the paper. Write an informative digest of the significant content and conclusions, not a mere description. Generally, the abstract should not exceed 3% of the text.

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3. **Mehler, W. R.** 1966. Further notes on the center median nucleus of Luys. In: *The Thalamus.* D. P. Purpura and M. D. Yahr, eds., Columbia University Press, New York, pp. 109–127.
4. **Tremblay, J. P., M. Colonnier and H. McLennan.** 1979. An electron microscope study of synaptic contacts in the abdominal ganglion of *Aplysia californica.* J. Comp. Neurol., **188:** 367–390.

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This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

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Journal of the Washington Academy of Sciences,
Volume 74, Number 4, Pages i–ii, December 1984

Commentary

Science Advancement Programs for Secondary School Students

Edward J. Finn

Department of Physics, Georgetown University, Washington, D.C. 20057

The scientific community has supported various programs for young people who show interest in scientific and technical matters. Who of us is not familiar with our local primary school's annual "Science Fair"? We become involved, whether a practicing scientist or not, when our child comes home with a need to produce a science project at the insistence of "teacher". Despite the forced atmosphere of a homework assignment, a few children (with appropriate assistance) do create interesting posters and/or demonstrations. This is only a part of a vast pool from which individuals with apparent interest and ability in the mathematical and scientific areas begin to be identified. Recall that each project is reviewed by a person who has had training and experience, the better projects are awarded recognition and usually rewarded by having the project entered in a second round of competition. The competition is refined again and again, culminating with an International Science Fair, which was held this past year in Columbus, Ohio in May of 1984. As witness to level of sophistication attained by the young people who reach the level of "international" competition, this issue of the Academy's Journal contains eight papers written by secondary school students. Each of these students was a Finalist in her/his respective field in Columbus, and the paper is based on their investigations. We trust you will find them not merely interesting in that young people can perform at such a high level of research, but truly remarkable in that many of these projects were not funded at the level usual for such research, nor were they performed in laboratories equipped with the latest tools.

The Science Fair project is only one of a number of programs sponsored by various organizations to help aspiring young people. Another event is the Westinghouse Science Talent Search, which is comprised of a rather stiff examination coupled with a written presentation of an independent science project. This year over 15,000 students entered the competition, and more than one thousand wrote their papers to complete their entries. From these fourty students will present their research and be awarded various scholarships after the judging. The purpose for this "Talent Search" is exactly that: to discover and develop scientific and engineering ability among high school seniors. It is not uncommon to find the names of Westinghouse finalists among the list of international finalists of the Science Fair competition.

The Washington Academy is involved in

the encouragement of science among secondary students in two ways. The Academy sponsors the Washington Junior Academy of Sciences, which is open to all Washington metropolitan area secondary students who are interested in scientific endeavors. The Junior Academy holds a number of meetings each year, primarily as field trips to scientific establishments in the region. These meetings serve to familiarize members with the facilities at the larger research laboratories as well as to band together to share information on possible sources of equipment and/or funding through grants or summer employment. The Academy also is co-sponsor of the Greater Washington Area Junior Science and Humanities Symposium. This two day symposium is designed to stimulate the interest of secondary school students (who have been carefully nominated by their school as having scientific potential) in science as a possible career, to put them in active contact with professionals in the various disciplines and to provide a measure of recognition within their own environment for academic excellence. These goals are performed in various ways: plenary sessions of the 300 participants with a major researcher who resides in the area; visitation in small groups to individual research laboratories; oral presentation of research papers by members of the local secondary school population. Teachers usually comprise about 20% of the total attendance so they may gain new insights into the communication of scientific principles and encourage them to return to their schools and search more carefully for the interested student who could perform basic research. As with all these competitions, the student presentors are invited to a National Junior Science and Humanities Symposium, with one presenting there—and from there a few of the National presentors are invited to attend the London International Youth Science Fortnight where approximately 400 students from 30 nations are gathered to exchange ideas and enjoy each other's company.

There are other programs available for the interested student of science, many sponsored by a scientific Society—such as the American Mathematical Association's sponsorship of the Mathematical Olympiad. Let it be enough to say that after some of the following papers have been read, it will be apparent that we all have a responsibility to see that opportunities are constantly made available to such individuals so they may grow intellectually at a pace commensurate with their ability.

Dr. Finn is a Professor of Physics at Georgetown University, a Fellow of the Washington Academy and present Director of the Greater Washington Area Junior Science and Humanities Symposium.

Journal of the Washington Academy of Sciences,
Volume 74, Number 4, Pages 85–96, December 1984

Inter-Relationships Between Dietary Fatty Acids and Indomethacin: Prostaglandin E_2 Synthesis, Mammary Tumor Growth, and Immune Responses

Cuong Viet Do

Formerly with The Oklahoma Medical Research Foundation

ABSTRACT

Studies were performed to determine the effects of dietary fat and indomethacin on: (a) fatty acid concentrations in blood serum; (b) Prostaglandin E_2 (PGE_2) production by splenic mononuclear cells; (c) growth of mammary tumors; (d) phagocytic activity of macrophages; and (e) cytotoxic activity of Natural Killer (NK) cells. Female, inbred, Wistar-Furth rats were fed semipurified diets containing 2, 5, 10, or 20% stripped corn oil. Indomethacin was administered in drinking water to give final dosage of 2.5 to 3.0 mg indomethacin/kg body weight/day. Feeding of diets and treatment with indomethacin began when rats were weaned (21 days of age), and continued until time of sacrifice at 35 or 50 days of age. Rats were divided into two groups. The first group was injected with 5000 mammary tumor cells into the right inguinal lymph node area, and was used to determine the first three parameters of the study. The second group did not receive tumor cells, and was used to determine the latter two objectives of the study. Results indicated: (a) fatty acid absorption was not influenced by indomethacin treatment; (b) linoleic acid concentrations in blood serum were significantly higher in rats fed high fat diets compared to rats fed low fat diets; (c) PGE_2 synthesis very significantly increased in untreated rats as dietary fat content increased; (d) indomethacin treatment very significantly abrogated PGE_2 production in all dietary groups; (e) tumor mass very significantly increased as dietary fat increased in untreated animals; (f) indomethacin treatment very significantly reduced tumor mass in all dietary levels; (g) phagocytic activity of macrophages very significantly decreased with high fat diets; (h) indomethacin very significantly increased macrophage activiɩy; (i) NK activity very significantly decreased as dietary fat content increased; and (j) NK activity very significantly increased with indomethacin treatment.

Introduction

A number of studies have shown a positive correlation between the incidence of mammary cancer and the intake of dietary fat in both humans[4,10,31,55,56,57,58] and laboratory animals.[4,46,49,50] Other studies[5,6,13,26] have shown that dietary fat increased the incidence of mammary tumors in rats induced with a single oral dose of 7,12-dimethylbenz(α)anthracene (DMBA). For example, Carroll et al.[5,6,13] reported that rats fed high fat diets, especially

unsaturated fats, developed a higher incidence of tumors which appeared after a shorter latent period compared to rats fed low fat diets or high saturated fat diets. Differences in tumor incidence were independent of small differences in caloric intake. These observations were confirmed by King et al.[26] who also noted that tumors grew more rapidly in rats fed diets containing high levels of polyunsaturated fat. Studies reported by Carroll and Khor[5] and Hopkins et al.[23] are consistent with the hypothesis that dietary fat is a promoter of tumorigenesis, since DMBA-induced tumor incidence depended more on diets fed after the carcinogen than on diets fed before. Data summarized by Vitale and Broitman[53] suggested that diets containing high levels of unsaturated fat were better promoters of tumorigenesis relative to diets containing high levels of saturated fat. These observations suggest that unsaturated fat diets were more immunosuppressive.

Ip and Sinha[24] excised mammary glands from rats fed diets containing either 20% or 5% corn oil. These glands were exposed to DMBA in organ culture before grafting into rats on either diets. The final tumor incidence in rats maintained on low fat diets varied from 20% to 28%, while incidence in rats on the high fat diet varied from 72% to 76%. Hopkins and West[22] reported that the transplantability of mammary adenocarcinoma was significantly higher in mice fed unsaturated diets compared to mice fed saturated diets. Similar observations were made in rats by Kollmorgen et al.[29] and Hillyard and Abraham[21] when using diets containing either 20% or 2% corn oil.

Plescia et al.[39] were the first to demonstrate that tumor growth *in vivo* was retarded when rats were given daily injections of indomethacin. Other investigators reported similar findings when mice were treated with indomethacin or other inhibitors of prostaglandin synthesis.[20,33,34] Indomethacin also inhibited tumor growth in rats exposed to chemical carcinogens which induced tumors of the gastrointestinal tract[36,40,41,42] and of the urinary bladder.[7] Cytotoxic drugs were more effective when used in combination with inhibitors of prostaglandin synthesis in treating tumors in mice[1] and rats.[43] In addition, indomethacin potentiated the effect of immune stimulants.[43]

While the suppressive effects of PGE_2 on various immune functions have been well documented,[2,3,11,15,17,18,46,54] several other relationships have not been established. This study attempted to establish the relationships between: (a) PGE_2 synthesis and dietary fat intake; (b) tumor growth and diet; (c) phagocytic activity of macrophages and diet; and (d) cytotoxic activity of Natural Killer cells and diet.

Materials and Methods

Rats

Inbred, Wistar-Furth, female, weanling rats (21 days old) were obtained from Harlan, Sprague Dawley (Madison, WI), and were housed in a temperature- and humidity-controlled facility with a 12 hour light:dark cycle. Rats were divided into two groups. The first group was used to measure tumor mass, PGE_2 concentrations, and serum fatty acids concentrations. The second group was used to determine the activity of macrophages and NK cells. Diets and indomethacin treatment were the same for the two animal groups.

Diets

Weanling rats were fed semi-purified diets containing 2, 5, 10, or 20% stripped corn oil. Diets were prepared by ICN Life Sciences, Inc. (Cleveland, OH). Diets were stored in sealed plastic containers in the dark and maintained at 4°C. Constituents of the diets are shown in Table 1. While caloric density varied from diet to diet, all rats were fed approximately 70 kcal/rat/day, and levels of ingredients were adjusted to maintain a constant nutrient:calorie ratio in all dietary groups.

Treatment with indomethacin

Indomethacin was dissolved in 95% ethanol (8 mg indomethacin/ml ethanol). This solu-

Table I.—Constituents of Diets

	20% fat diet			10% fat diet			5% fat diet			2% fat diet		
	g/100 g diet	cal	% of total cal	g/100 g diet	cal	% of total calories	g/100 g diet	cal	% of total calories	g/100 g diet	cal	% of total calories
Casein	24.40	97.60	21.17	22.15	88.60	21.36	20.92	83.68	21.38	20.00	80.00	21.16
DL-Methionine	0.60	2.40	0.52	0.54	2.16	0.52	0.52	2.08	0.53	0.50	2.00	0.53
Fat[a]	20.00	180.00	39.05	10.00	90.00	21.72	5.00	45.00	11.50	2.00	18.00	4.76
Vitamins[b]	1.22	4.88	1.06	1.10	4.40	1.06	1.05	4.20	1.07	1.00	4.00	1.06
Salts[c]	4.88	0.00	1.06[d]	4.40	0.00	1.06[d]	4.15	0.00	1.06[d]	4.00	0.00	1.06[d]
Choline	0.12	0.48	0.11	0.11	0.44	0.11	0.11	0.44	0.11	0.10	0.40	0.11
Alphacel	4.88	0.00	1.06[d]	4.40	0.00	1.06[d]	4.25	0.00	1.09[d]	4.00	0.00	1.06[d]
Sucrose	43.90	175.60	38.09	57.30	229.20	55.26	64.00	256.00	65.41	68.40	273.60	72.38
Totals	100.00	460.96	100.00	100.00	414.80	100.03	100.00	391.40	100.00	100.00	378.00	100.00

[a]Stripped corn oil (Eastman).
[b]Vitamin fortification mixture of ICN Life Sciences Company.
[c]AIN-76 salt mix.
[d]Expressed as g/total cal.

tion was diluted with 400 ml drinking water (tap water). Final concentration of indomethacin in drinking water was 20 mg/liter, and the final concentration of ethanol in drinking water was 0.25%. Control rats were given only 0.25% ethanol in their drinking water. Indomethacin consumption was determined to be 2.5 to 3.0 mg indomethacin/kg body weight/day.

Tumor cells

Mammary tumor cells were originally induced in Wistar-Furth, inbred, female rats with DMBA. Metastases were observed in lymph nodes of rats which have been given partial-body radiation after exposure to DMBA.[25] These metastatic mammary tumor cells were serially transplanted into Wistar-Furth, female, inbred rats, and were kindly provided by Dr. Untae Kim (Buffalo, NY). Tumor cells (5×10^3 in 0.2 ml phosphate buffered saline, pH 7.0) were injected into the right inguinal lymph node area of weanling female rats of the first animal group. Rats of the second animal group did not receive tumor cells.

Autopsies

Rats were maintained until 35 or 50 days of age, at which time rats of the first animal group were sacrificed. At this time, blood was drawn and serum extracted to be used for fatty acid analysis and media supplementation. Spleens were excised and single cell suspensions prepared for use in PGE_2 assays. Lymph nodes (right and left inguinal), right and left axillary, lumbar, messenteric, and thymus) were excised, weighed, and histologically evaluated for tumor presence. Other tissues removed and evaluated for possible tumor involvement include lungs, kidneys, brain, gastrointestinal tract, and bone. However, this paper only deals with metastatic involvement in lymph nodes. Rats of the second animal group were sacrificed at 50 days with the procedures discussed below under "Phagocytic activity of macrophages," and "Preparation of spleen cells for NK assays."

Assays for PGE_2 in cultured spleen cells

Spleens were removed from 50 day-old rats, and single cell suspensions were prepared from these spleenocytes by placement in plastic petri dishes containing RPMI 1640 media supplemented with 10% fetal bovine serum and 10% autologous serum (20% total serum). Cells were cultured in 10 mls of media (1.7×10^7 cells/ml) for 24 hours with pH controlled at 7.0. Control dishes contained only media and serum. When incubation was complete, supernatants were removed and suspended cells separated with centrifugation. 3 ml samples of supernatants were acidified, extracted with ethyl acetate, and dried under nitrogen.[47] The dried extracts were dissolved in 1 ml of benzene:ethyl acetate:methanol (70:30:5 v:v:v) and applied to a 2 gram silicic acid column that have been equilibriated with benzene:ethyl acetate (70:30 v:v). Neutral lipids were first eluted in 10 ml benzene:ethyl acetate (70:30 v:v), PGA-PGB in 10 ml ethyl acetate, and PGE with an additional 15 ml ethyl acetate:methanol (93:7 v:v).

The fraction containing PGE_2 was dried under nitrogen and resuspended with 1 ml methanol. A 0.1 ml sample of the resuspended PGE_2 fraction was assayed after appropriate dilution with 0.1M sodium phosphate buffer (pH 7.6). In each assay, a highly specific PGE_2 antibody (Pasteur Institute, Paris) was added to either samples or standards (2-2000 pg) in the presence of ^3H-PGE_2 tracer (7,000 cpm). The validity and reliability of the antibody have been documented previously.[10] The PGE_2 antibody had a 3.2% cross-reactivity with other prostaglandin species. Incubation occurred at 4°C for 8 hours. Bound and free antibody were then separated by the addition of 0.5 ml dextran-coated charcoal (25 mg dextran, 250 mg charcoal, 100 ml phosphate buffer).

Analysis of serum fatty acids

2 mls of serum were extracted according to the method of Folch et al.[12] Briefly, 2 ml serum samples were added to a 50 ml separatory funnel containing 10 volumes of cold chloroform:methanol (2:1 v:v). The serum

was extracted with vigorous shaking for 3 minutes then allowed to stand at room temperature for 30 minutes. One-fifth volume of 0.5% NaCl solution and an internal standard (methyl arachidate) equal to approximately 10% of the total lipids being extracted was added, and the mixture was reextracted as above.

The 2-phase extraction system was held in the dark at 4°C overnight for extraction and phase separation. The lower chloroform layer was transferred to round-bottomed flask, and the flask connected to a vacuum rotary-evaporative system and evaporated to dryness. Absolute ethanol was added to the flask (1 to 2 ml) to remove residual water and again evaporated to dryness.

Fatty acid methyl esters were prepared from the lipid samples. The chloroform was evaporated from the sample and 1 ml BF_3 : methanol (1 : 1 v : v) added. The sample was boiled for 15 minutes in tightly capped test tubes with Teflon-lined caps. After cooling, 1 ml water and 2 ml chromatoquality hexane were added, and the mixture was extracted using 90 seconds of vigorous shaking with a vortex laboratory mixer. The layers were allowed to separate, the hexane layer was removed, and 2 additional hexane extractions performed, each being removed and combined with the first. The combined hexane extractions were evaporated to dryness under vacuum, and the fatty acid methyl esters assayed at 190°C with N_2 as carrier at 40 ml/minute.

Phagocytic activity of macrophages

At 50 days of age, rats of the second animal group were injected with a 3 ml suspension of microbeads stained to floresce under florescent microscopy (1.2×10^6 beads/ml phosphate buffered saline) into the peritoneal cavity. Peritoneal exudate cells were obtained from individual rats under anesthesia 24 hours later. Rats were infused with 30 ml phosphate buffered saline (PBS, 37°C) intraperitoneally. 10 minutes later, the exudate was recovered by placing a 15-gauge needle into the cavity and collecting the fluid by gravity flow into an ice-cold polyethylene container. The exudate was centrifuged for 5 minutes at 800 rpm and 4°C, and the cells were washed four times with ice-cold PBS in order to terminate phagocytosis and remove nonbound, nonphagocytosed microbeads.

The number of cells present in the volume were determined by coulter counter. Representative samples of the volume were examined under florescent microscopy, and the number of florescent beads counted. The number of macrophages containing beads were divided by the total macrophage population to determine the percent of phagocytosis.

Preparation of spleen cells for NK assays

Spleen were excised, and single cell suspensions prepared in RPMI 1640. Adherent cells and macrophages were removed from spleen cell suspension according to the modified method of Garvin.[19] Briefly, 10 ml plastic pipettes (Falcon Products, Cockeysville, MD) were filled with 10 ml plastic beads (Separ-Aid, J. T. Baker, Bethlehem, PA) and washed with 15 ml RPMI 1640. The columns were loaded with 3 ml of spleen cells (2×10^7 cells/ml), stoppered with plastic caps, and incubated for 30 minutes at 37°C. The caps were removed and the non-adherent cells collected along the column wash of 6 ml media. The cell concentration was adjusted to 3×10^7 cells/ml.

Non-adherent spleen lymphocytes were further separated using discontinuous Percoll density gradient centrifugation. Step gradients were constructed by layering 26%, 50%, 55%, 60%, and 65% Percoll solutions into conical centrifuge tubes (Corning, Corning, NY). Lymphocyte suspensions (2×10^7 cells) were layered into the gradient and centrifuged for 30 minutes at 800 rpm and 15°C. The lymphocytes occurring at each Percoll density fraction were collected, counted, and tested for NK activity.

NK activity assay

0.1 ml YAC-1 tumor cells (1×10^5 cells) was added to triplicate wells of microtiter

plates. Spleen cells (2×10^5 cells) obtained from the 55% Percoll fraction was also added to each well. This resulted in an effector (spleen cells) to target (YAC-1 cells) ratio of 2:1. Effector and target cells were also cultured alone to measure spontaneous proliferative activity. Cells were cultured for 16 hours, followed by the addition of 1.0 μCi of [6-^{3}H]thymidine (specific activity 15 ci/mmol, New England Nuclear, Boston, MA). After an additional 3.5 hours of incubation, cells were harvested onto glass fiber filter strips using a multiple automated sample harvestor, and dried. The cells were transferred to scintillation vials and 10 ml scintillation fluid added. The amount of [6-^{3}H]thymidine incorporated into the cells was determined by liquid scintillation counting. Natural killer cell activity was expressed as the percent of [6-^{3}H]thymidine of spleen cells cultured with YAC-1 tumor targets compared to YAC-1 cells cultured alone.

Results

Serum fatty acid concentrations were not affected by indomethacin, as measured by ten fatty acid species (Figure 1). Additionally, most species were not affected by dietary fat. The concentration of linoleic acid was very significantly ($p < .001$) higher when rats fed either 10% or 10% were compared to 2% diets. Conversely, oleic concentrations very significantly ($p < .001$) decreased as dietary fat content increased. The total serum fatty acid concentration was not affected by either fat or indomethacin.

PGE_2 synthesis by cultured spleen cells very significantly ($p < .001$) increased as dietary fat content increased (Figure 2). Treatment with indomethacin very significantly ($p < .001$) reduced PGE_2 production in all dietary levels. PGE_2 levels in the indomethacin-treated group did not change as dietary fat level increased.

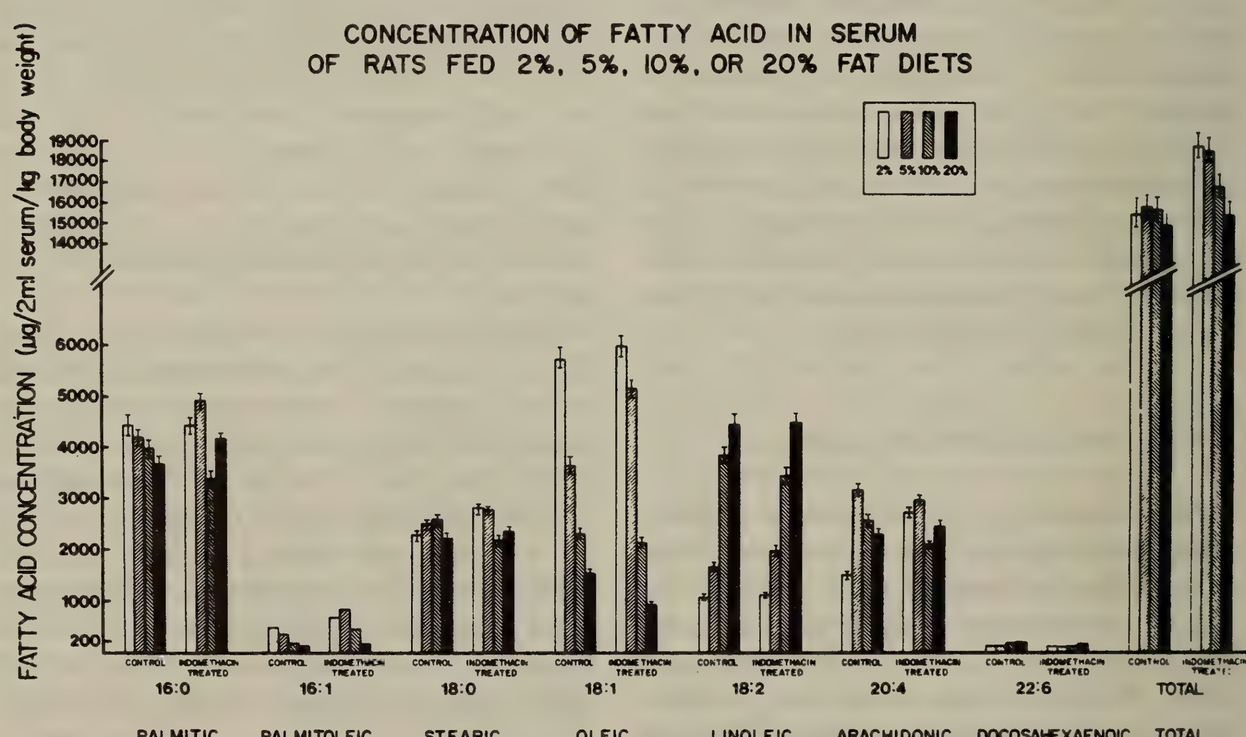

Fig. 1. The concentrations of serum fatty acids are expressed in μg/2 ml serum/kg body weight ± one standard deviation. Diets were started when rats were 21 days old, and rats were sacrificed at 50 days of age. Total fatty acid concentrations were based on the sum of ten species (those shown and 14:0, 22:4, 24:1). Except for two species, fatty acid concentrations did not differ significantly as dietary fat content increased. Linoleic acid very significantly ($p < .001$) increased as dietary fat content increased and oleic acid very significantly ($p < .001$) decreased as dietary fat increased. Total serum concentrations remained constant as dietary fat content increased.

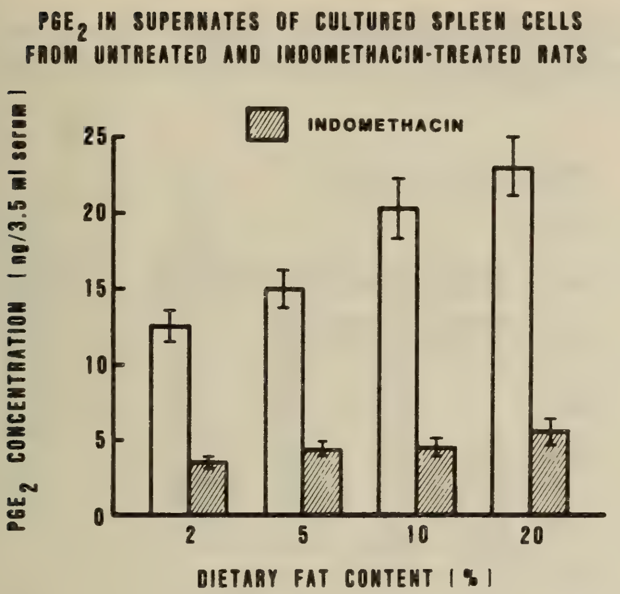

Fig. 2. Mean values ± one standard deviation are expressed in ng PGE_2 ml spleen cell supernatant. Spleens were taken from 50 day old rats fed either 2, 5, 10, or 20% fat since weaning. PGE_2 concentrations increased very significantly ($p < .001$) as dietary fat content increased, and indomethacin very significantly ($p < .001$) abrogated PGE_2 production.

Total body weight increased very significantly ($p < .001$) as dietary fat content increased (Figure 3). Carcass weight (total weight minus tumor weight) also increased very significantly ($p < .001$) with dietary fat content. At 50 days of age, untreated rats were moribund and had significantly ($p < .05$) smaller body weight than indomethacin-treated rats. Tumor involvement in the mesenteric and lumbar nodes frequently caused partial obstruction of the ureter and/or the intestine. Rats treated with indomethacin had much less tumor burden in these areas, and food consumption was higher in these rats.

Primary tumor mass (right inguinal lymph node) of rats at 35 days of age were smaller than rats at 50 days of age (Figure 4). The slope of the lines connecting these two time periods revealed the relative growth rates, but statistical analyses were not performed on the rates due to the limited sample size. However, growth rates of rats fed 20% diets were sub-

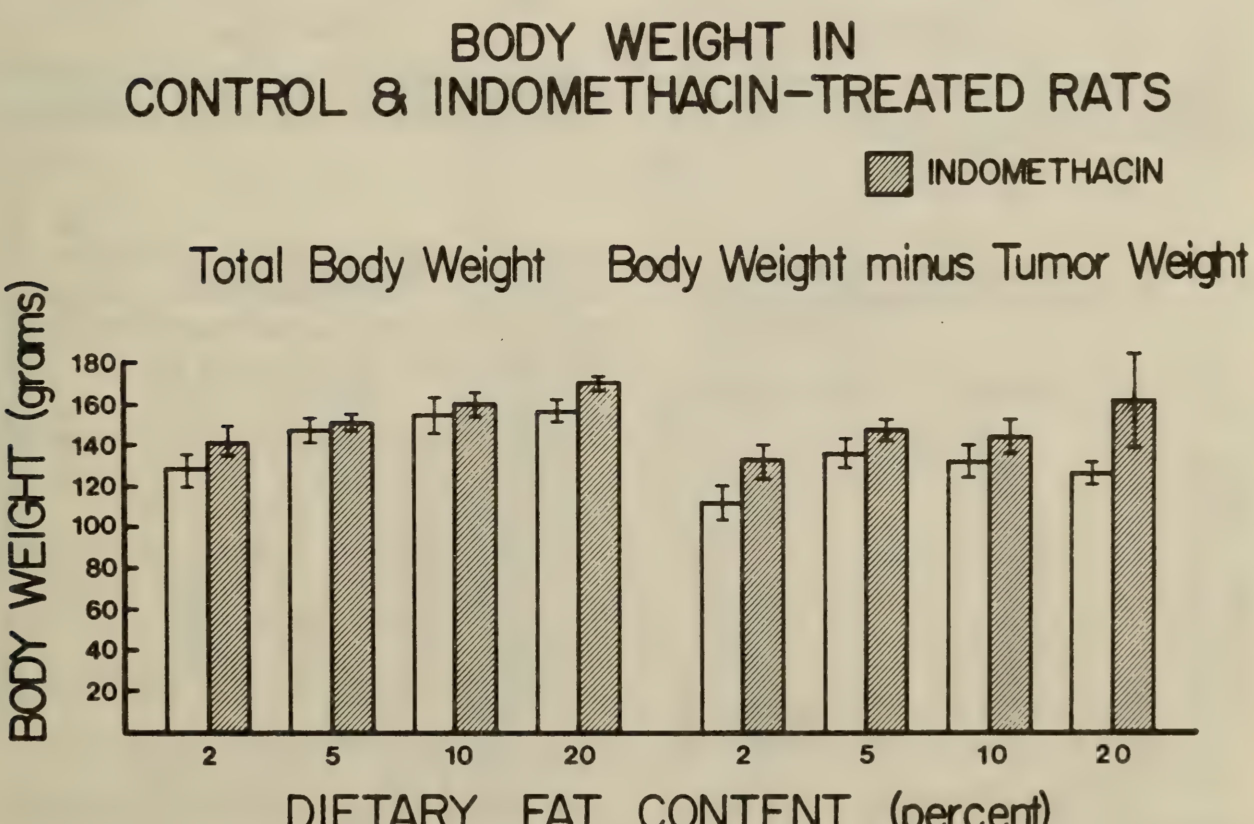

Fig. 3. The body weights of control and indomethacin-treated rats are expressed in grams ± one standard deviation. Diets and treatment with indomethacin started when rats were at 21 days of age. The above data was taken when rats were at 50 days of age. Body weights increased very significantly ($p < .001$) as dietary fat content increased, and indomethacin significantly ($p < .05$) increased body weight.

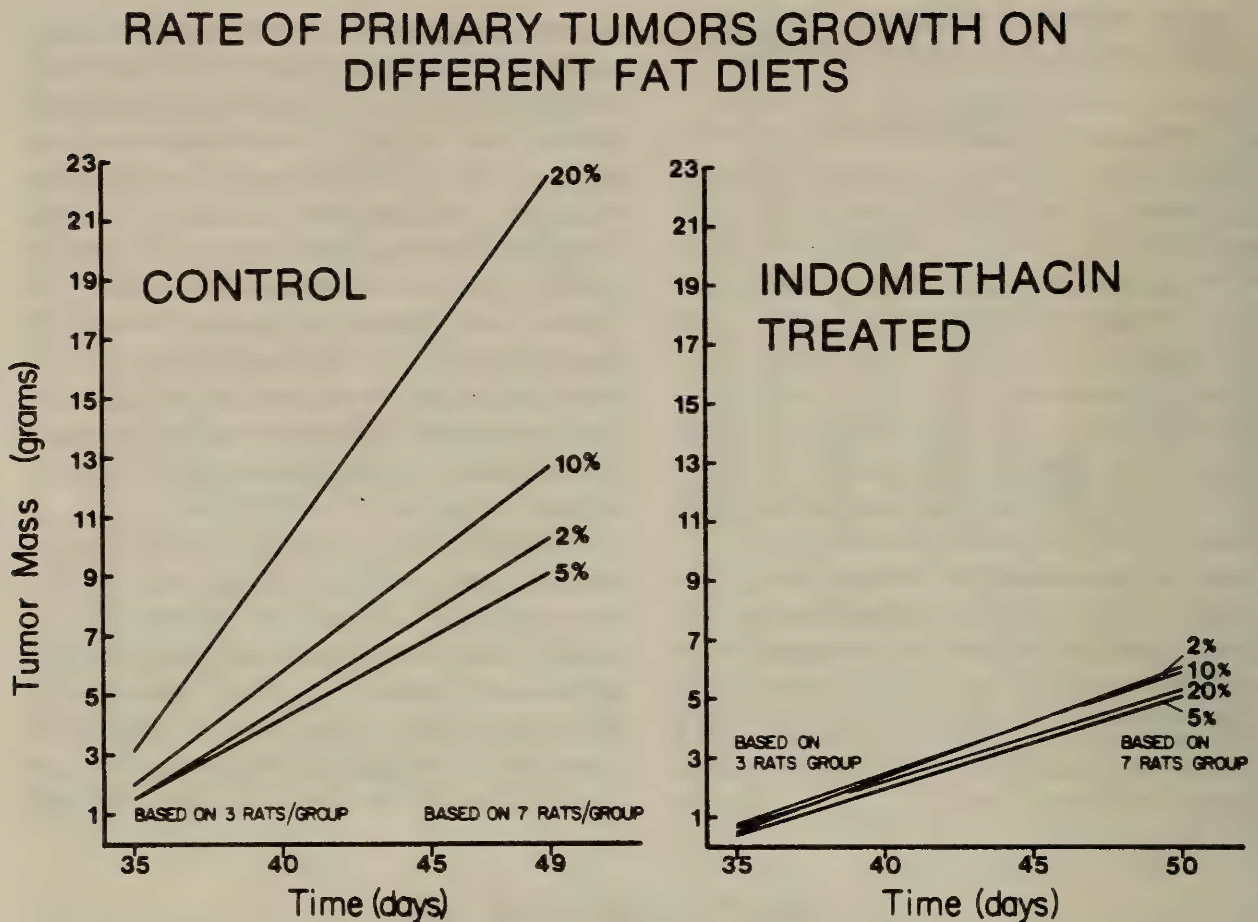

Fig. 4. The growth rat for primary tumor site (right inguinal lymph node) are shown for control and indomethacin-treated rats. Three rats were sacrificed at 35 days of age, and 7 at 50 days of age. No statistical analyses were performed due to limited sample size.

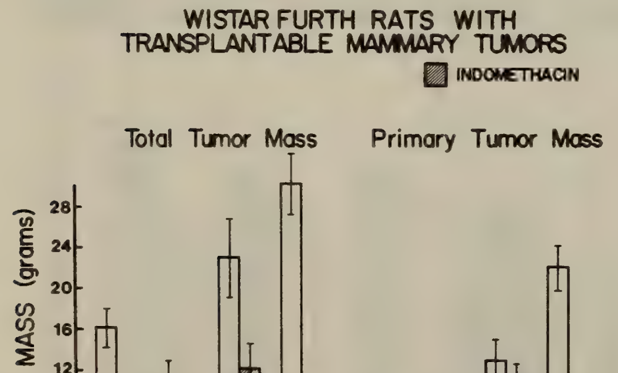

Fig. 5. The total and primary tumor mass of rats sacrificed at 50 days of age are expressed in grams ± one standard deviation. Total and primary tumor masses very significantly ($p < .001$) increased as dietary fast content increased, and indomethacin very significantly ($p < .001$) reduced tumor masses.

stantially higher than any other untreated dietary groups. No differences were observed among groups of the indomethacin-treated rats. The tumor mass at 50 days of age very significantly ($p < .001$) increased as dietary fat content increased (Figure 5), and indomethacin very significantly ($p < .001$) decreased the tumor mass in all dietary groups.

Figure 6 illustrates the phagocytic activity of macrophages from peritoneal exudates. Phagocytosis very significantly ($p < .001$) decreased as dietary fat content increased, and indomethacin treatment very significantly ($p < .001$) increased macrophage activity in all dietary groups. Increased uptake of [6-^{3}H]thymidine by YAC-1 tumor cells indicates that cytotoxic activity of NK cells very significantly ($p < .001$) decreased as dietary fat content (Figure 7), and indomethacin very significantly ($p < .001$) increased NK activity.

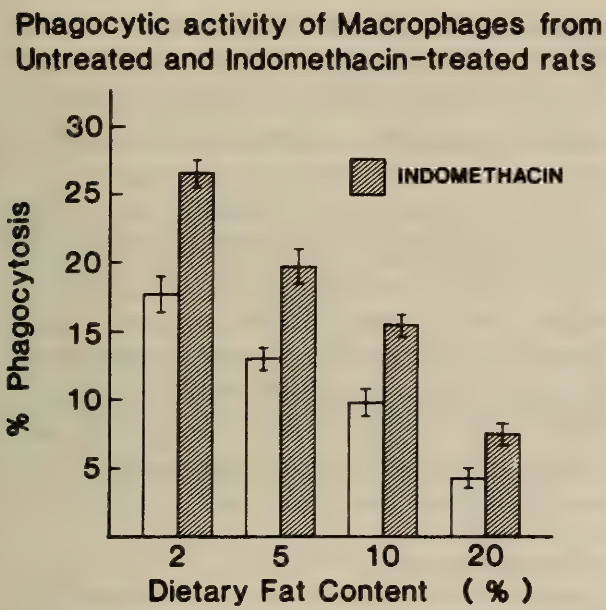

Fig. 6. Phagocytic activity of macrophages are expressed as percent of phagocytosis (means ± one standard deviation) for control and indomethacin-treated rats. Macrophages were allowed to phagocytose microbeads, which were harvested and measured for macrophage activity. Dietary fat very significantly ($p < .001$) decreased macrophage activity, and indomethacin very significantly ($p < .001$) increased macrophage activity.

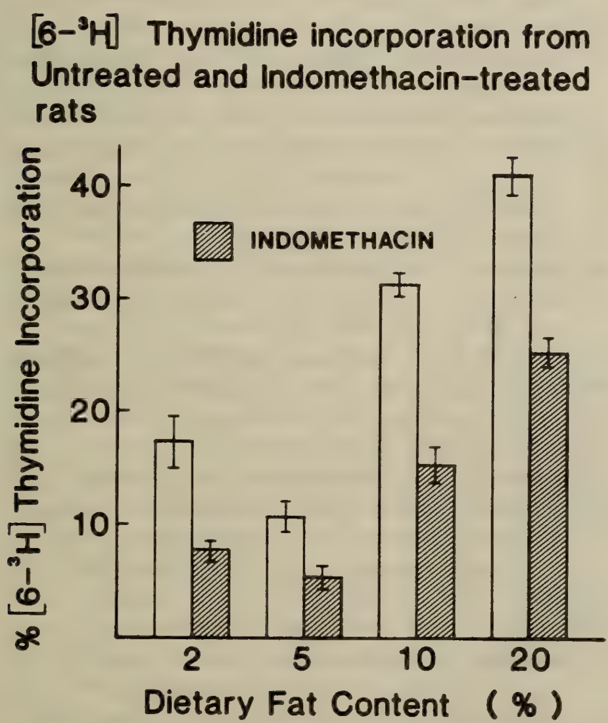

Fig. 7. The activity of NK cells were measured as a function of the uptake of [6-^{3}H]thymidine. Means ± one standard deviation are expressed for control and indomethacin-treated rats. Uptake very significantly ($p < .001$) increased as dietary fat content increased, and indomethacin very significantly ($p < .001$) decreased uptake. Increased uptake is indicative of decreased NK activity.

Discussions

Results from these studies indicate that the production of PGE_2 by splenic mononuclear cells and the growth of mammary tumors very significantly increased as dietary fat content increased, phagocytic activity of macrophages and cytotoxic activity of NK cells very significantly decreased as dietary fat increased, and indomethacin treatment very significantly decreased PGE_2 production and tumor growth and increased macrophage and NK activity.

Fatty acids concentrations were measured in serum and serves only as an indicator of the cellular membrane content and intestinal absorption. In indomethacin-treated rats, a concern existed that indomethacin might influence the gastrointestinal tract and ultimately absorption. Analysis of blood serum reveals that fatty acid levels were similar between untreated and indomethacin-treated rats, thus the results suggest that the possible effects of indomethacin were not observed in this particular study. Increased linoleic levels as dietary fat content increased is expected, for rats are being fed increasing quantities of corn oil which binds linoleic acid on two of its three side chains. No explanations, however, can be formulated to explain the decrease in oleic concentrations.

This study dealt only with the production of PGE_2 by splenic cells. However, PGE_2 production by other cells, particularly mammary tumor cells, may also be increased by dietary fat. No attempts were made to measure PGE_2 synthesis in lymph nodes containing tumor cells. Lymph nodes vary considerably in the amount of infiltrating lymphocytes and monocytes/macrophages. Hence, determination of the PGE_2 source would be difficult in this heterogeneous cell population. However, Roland et al.[45] assayed for PGE_2 in freshly excised human breast cancer, in both primary and metastatic lesions. They suggested that elevated levels of PGE_2 could be used as markers of high metastatic potential of neoplastic cells in breast cancer. Pelus and Brockman[37] reported that peritoneal macrophages from tumor-bearing mice released significantly more PGE_2 compared to macro-

phages of control mice. On the other hand, Harvey et al.[19] concluded that circulating levels (venous blood) of PGE_2 did not correlate with the non-specific immunosuppression seen in cancer patients. Hence, PGE_2 concentrations in the immediate environment of the tumor is more indicative of tumor growth, invasion, or metastasis compared to PGE_2 concentrations in body fluids.

The growth rates between 35 and 50 days of age are only indicative of the relative or mean rate. If more points were taken over the interval, a biological exponential curve would be expected. The observation that indomethacin inhibited tumor growth at 50 days of age is consistent with other investigators.[7,20,33,34,36,39,42] The fact that indomethacin was effective only in immunologically competent mice argues against indomethacin being a toxic antitumor agent.[50]

Kollmorgen et al. indicated that the growth promoting effects of diets containing high levels of unsaturated fat may be due, at least partially, to an increased PGE_2 synthesis. This, in turn, may cause immune suppression. Hence, immune defense mechanisms which potentially controlled tumor growth may be severely compromised. Other studies[14,27,28,30,51,54] have reported that DMBA-induced mammary tumors were apparently influenced by the immune system. Other investigators[3,8,35,38,53] suggest that decreased macrophage activity may be due to increased PGE_2 production. Results from this study, perhaps the first *in vivo* study, also found decreased macrophage activity with increasing fat content and PGE_2 concentrations.

The measurement of NK activity was made in titer wells with YAC-1 tumor cells. NK cells of splenic origin were cultured with target tumor cells and [6-^{3}H]thymidine. Unless the NK cells destroy the target tumor cells, tritiated thymidine would be incorporated into the tumor cells' DNA during replication. Uptake of [6-^{3}H]thymidine increased as dietary fat content increased, thus suggests a compromise in NK activity. Indomethacin decreased the uptake, indicating enhanced NK activity. Mihas et al. indicated that the effects of fatty acids on immune-related cells do not seem to be toxicity. Vitale and Broitman[53] suggested that the mechanisms may be an alteration of membrane fluidity which may alter the configuration of receptor sites or decreased macrophage action which could affect antigen-lymphocyte interactions.

While indomethacin exhibited the ability to reduce tumor growth and PGE_2 production and increase macrophage and NK activity, studies need to be conducted to consider its effects on other products of the cyclooxygenase and lipoxygenase pathways before the inhibitor can be effectively considered for addition to clinical therapeutic protocols.

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Neural Mechanisms of Vision and the Evolution of the Alphabet

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ABSTRACT

Eight subjects were tested on visual discrimination performance of pairs of letters from the Roman alphabet, and two of its antecedent alphabets, the Etruscan and Early Phoenician. The number of errors per trial decreased at the rate of .34% per century ($p < .05$). These data indicate that the human visual system probably has influenced the evolution of the alphabet. The performance of an original computer simulation of the feature detector model of form perception on the task of letter discrimination was compared to human performances. Unique non-linearities of the model's performance may have implications for the effect of the magnitudes of neuronal excitory thresholds on perceptual performance.

Introduction

The first part of this project evaluated the hypothesis that the neurophysiological characteristics of the human visual system have had significant influence on the evolution of the alphabet. The second part developed a computer simulation of the Hubel and Wiesel feature detector model of the neural mechanisms of visual form perception and compared its performance to human performances on the task of letter discrimination.

Pigeons and humans demonstrate similar patterns of letter discrimination within the modern Roman alphabet,[1] suggesting that these patterns are a manifestation of the characteristics of the neural mechanisms of form perception, rather than visual experience[2] or higher cognitive functions. If, in addition, the rate of discrimination errors for letter pairs has systematically decreased across the evolutionary antecedents of the Roman alphabet, then it is likely that the neural mechanisms of form perception have had some influence on alphabetic evolution.

Two rival models of the neural mechanisms of form perception currently exist;[3] however, because of the neurophysiological and perceptual complexities of the visual system,[4–6] it is virtually impossible to assess the relative validity of these models by simple inspection. If it has evolved toward visual processing efficiency, the alphabet would offer a particularly effective collection of stimuli to test a model of the neural mechanisms of form perception. Moreover, the correlation between the performance of a computer simulation derived from neurophysiological data and human performances on the task of letter discrimination should provide a particularly accurate measure of the validity of that model.

Methods

I. Human Psychophysical Study

Every letter which has a continuous archeological record,[7] was used in a discrimination paradigm with itself and with the letters with which it is most and least often confused.[8] All subjects were tested on the Early Phoenician alphabet. Three were also tested with the Early Etruscan alphabet and another three were tested on the Roman alphabet (Times Roman typeface). Two subjects were tested with all three alphabets. Figure 1 presents the three alphabets used. One half of the stimuli were the same, and a quarter of the different pairs were rarely confused by humans. This procedure diminished bias due to subject anticipatory responses.[9] Letter pairs were photographed on a high-contrast film (Kodak Technical pan 2514) from Diringer[7] using a copy stand, developed, and mounted in slide mounts. Eight subjects (ages 15–18) with normal or corrected vision were seated 2.5 m from a screen onto which images of size 4cm × 8cm, subtending a visual angle of one degree, were projected using a Kodak Carousel slide projector set at the low light intensity with a Polaroid shutter. A blue gelatin filter (Kodak Wratten gel #29) was placed in front of the shutter to diminish the visual contrast afterimages. The brightness of the image was 60 candles/sq. m. This value is higher than reported by other investigators because of the use of the blue filter in this study. The ambient light level of the room was 6 lux.

Initially, each subject participated in a calibration procedure where the shutter speed was adjusted so that all subjects made between 15%–25% discrimination errors on a standard set of stimuli (shutter duration ranged from 30–60 msec). The subject was then presented with 136 pairs in a randomly selected predetermined order in ten second intervals with a 30 second break between every 34. Most subjects participated in two trials in the second of which the order of presentation was reversed. Each subject signed an Informed Consent Statement approved by the IRB.

II. Computer Simulation of the Feature Detector Model

The computer simulation of the feature detector model was developed on a DEC VAX 11/780. An Optronics P-1000 densitometer was utilized to digitize the letters (Black Helvetica medium capitals, 38mm high) into matrices containing two levels of contrast. Several algorithms, representing segments of the feature detector model[10–13] were written in Fortran 77.

Initially, in the computer program, an edge-detecting algorithm,[14] simulating the computational characteristics of some retinal ganglion cells is applied to the images. The program searches for simple features (bars at four orientations), representing the organization of several cortical receptive fields. A parameter, SIMPCRIT, is the criterion for de-

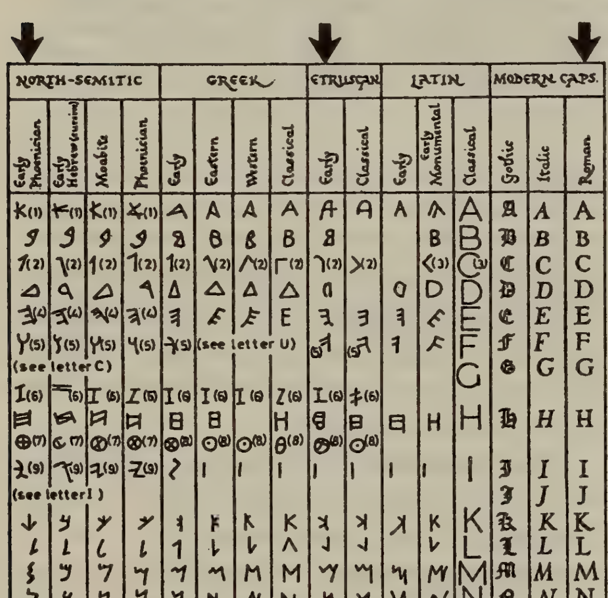

Fig. 1. The Roman alphabet and its antecedent alphabets. As adapted from D. Diringer, *The Alphabet: A Key to the History of Mankind*, 3rd. Ed. New York, Funk and Wagnalls 1968.

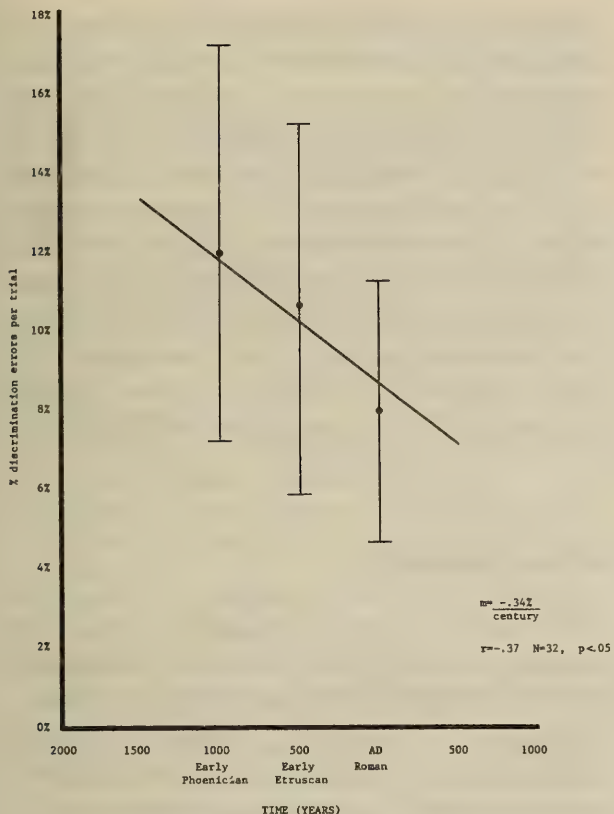

Fig. 2. The percentage discrimination errors per trial within an alphabet as a function of its time of initial predominance. Within a tachistoscopic paradigm, 8 subjects were tested on letter discrimination. 3 were tested on the first and second alphabets, 3 on the first and third, and 2 on all three.

termining the existence of a feature within a specific region of the image. SIMPCRIT represents the magnitude of the excitory threshold of the feature detector neurones. The features, themselves small matrices, are dot multiplied through all regions of the digitized image. If the value of the dot product exceeds SIMPCRIT, then the feature is defined as present within that region. Values are then added to another matrix, which is a linear transformation of the original matrix, to signify the redundancy of identification for each point. Using the Point Biserial Correlation Coefficient (PBCC),[15] the correlation between this matrix of redundancy levels and all digitized letters is calculated. The higher the correlation, the more accurate the discrimination. Finally, the Pearson Product Moment Correlation (PPMC) between the PBCC for each letter and human performances on each letter[8] is determined, and the mean of the PPMC values is calculated.

Results

The results of Part I are displayed in Figure 2. The abscissa represents historical time, with each alphabet located along the continuum according to its approximate time of initial predominance.[7] The ordinate represents the mean percentage confusions per experimental trial for all subjects. The slope of the linear regression line, calculated using the least squares technique, is $-.34\%/\text{century}$. The correlation between percent discrimination errors per experimental trial and historical time is $-.37$. The probability that this result could have been due to chance alone is less than .05 or one in twenty.[16] Only one of eight subjects had significantly more confusions on a later alphabet than on an earlier one.

The results of Part II are illustrated in Figure 3, which shows the correlation of the

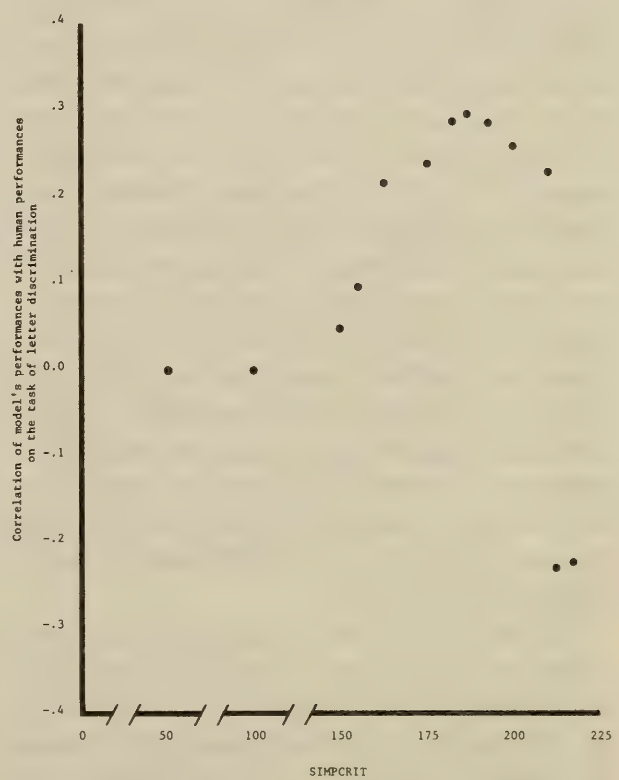

Fig. 3. Correlation between computer model's performances with human performances on the task of letter discrimination as a function of a parameter of the model, SIMPCRIT, which represents the magnitude of the excitory thresholds of the theoretical neurons of the model. The maximum correlation between the computer simulation of the Hubel and Wiesel model of form perception with actual human performances was .2975 at SIMPCRIT-187.0. The extreme values probably reflect the characteristics of the simulation rather than of the model.

computer simulation's performance with human performances on the task of letter discrimination as a function of SIMPCRIT. The graph demonstrates that the effect of SIMPCRIT on perceptual performance of the model is non-linear; the correlation with human performances rises to a maximum level of .2975 at SIMPCRIT-187 and then sharply falls. Limited quantities of data were collected because of the large computational requirements of the simulation.

Discussion

Although previous studies on the evolution of the alphabet[7] have not considered the neurophysiology of the visual system, the results obtained in this project (Fig. 2) seem to indicate that the neural mechanisms of form perception have played a significant role in the evolution of the Roman alphabet. Additional factors, such as the introduction of new technologies and the goals of ease and speed in writing, have certainly also had important influence on the evolution of the Roman alphabet;[7,17] thus the correlation between percent discrimination errors and historical time is not particularly high. Other investigators[18–20] have used letter discrimination as a metric to assess the validity of different models of the neural mechanisms; these results greatly reinforce the rationale of their paradigm. The results also suggest that it may be possible to design an ''optimal'' alphabet or more effective reading strategies,[21] once the organization and characteristics of the neural mechanisms are established.

While it is commonly accepted that neurones have an excitory threshold,[22] the effect of the level of this threshold, SIMPCRIT in the present model, on perceptual performance is evident in Figure 3. These findings reinforce the notion that the magnitudes and nonlinearities of neuronal excitory thresholds may significantly effect the performance of both theoretical and physiological neural networks.[22,23] The maximum correlation between human and computer model performances was .2975, somewhat lower than correlations for other models.[19,20] This difference could be accounted for by the small feature set employed[24]—the result of limited available computational resources—and thus does not reflect upon the actual validity of the Hubel and Wiesel feature detector model. Perhaps with a larger repertoire of features and more efficient computational algorithms, a more definitive analysis of the validity of the model could be completed. It is hoped that the letter discrimination paradigm will be applied to other proposed models of the neural mechanisms[24–27] to assess their validity.

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Hydra Reaggregation: A Rapid Assay to Predict Teratogenic Hazards Induced by Environmental Toxicity

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ABSTRACT

Before drugs, chemicals, and food additives are safety certified, they need to be tested in lengthy and expensive experiments. Such evaluation, however, does not keep up with the rapid development and production of new compounds. The purpose of this study, therefore, was to design, develop, and validate a new rapid assay to simulate embryogenesis and to determine the teratogenic potential of chemicals.

After testing many organisms, adult *Hydra attenuata* were used to evaluate the toxicity of several substances, including salicylic acid, lithium chloride, 2,4,5-trichlorophenoxyacetic acid, and Agent Orange. Each chemical's lowest toxic adult and ''embryo'' dosages were determined, through a series of 28 tests, to within one-tenth of a log concentration. Unique methods of tissue culturing of ''embryo'' hydra were developed to dissociate *Hydra attenuata* into their component cells and to form pellets which were ejected into reaggregation media containing specific concentrations of the test substances. While studying, at six time intervals, the growth reactions of adult and ''embryo'' hydra exposed to the chemicals, numerous controls were maintained.

Through an analysis of the results, validation by comparison with published rodent studies, and statistical verification, it may be noted that the *Hydra attenuata* assay is a viable screening technique which can predict the magnitude of a chemical's toxicity to developing organisms. Since many compounds cannot be adequately tested by traditional methods before being distributed within the environment, this new assay will identify those which mandate further testing before dissemination.

Introduction

The teratogenic potential or developmental mutagenicity of drugs, chemicals, and food additives is routinely tested in lengthy and expensive experiments which call for administration of a test substance to pregnant rodents during the period of major organogenesis. Military and industrial facilities are introducing new chemical compounds at such an increased rate, however, that the absence of rapid and inexpensive means for detecting teratogenic hazards is a major obstacle in society's efforts to make safety evaluations of chemicals.

The purpose of this study, therefore, was to design, develop, and validate a rapid assay

which would simulate embryogenesis and determine the teratogenic potential of chemicals. Hydra, the most primitive organism with complex structures, were chosen as the experimental animals because they exhibit, during regeneration, many of the phenomena required of a zygote in becoming an embryo and then a fetus. Some of the developmental cell processes exhibited by the regenerating hydra are: changes in cell size and shape,[1] spatial orientation,[2] cell migration,[3] intercellular matrix formation,[4] cell division and differentiation,[5] and organ field[6] and tissue[7] formation.

It was hypothesized that this new hydra assay could be used as a screening technique to identify chemicals potentially dangerous to an organism's developmental processes. Such a procedure would prioritize new substances according to their toxicity and their need for further study by more elaborate means.

Procedure

Three cultures of adult *Hydra sp.* were continually maintained within separate, aerated tanks regulated at a constant temperature of 21°C, using a method[8] which included daily feeding with iodine treated brine shrimp and complete tank draining 5 hours after feeding. Each tank contained hydra media (pH 7) which consisted of 0.147 g $CaCl_2$, 0.115 g TES, and 0.004 g EDTA dissolved in 1 liter distilled water.

Because extensive attempts using *Hydra littoralis* were unsuccessful, adult *Hydra attenuata*[9] were used to evaluate the toxicity of lithium chloride, salicylic acid, acetaminophen, lead dioxide, carbon tetrachloride, formaldehyde, 2,4-dichlorophenoxyacetic acid (2,4-D), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and Agent Orange (50% 2,4-D and 50% 2,4,5-T). Each chemical's lowest toxic dose was identified and verified to within one-tenth of a log concentration through a series of twenty-eight tests which were divided into four experiments. Experiment I determined the lowest toxic whole-log concentration by exposing hydra to solutions ranging from 0.0 mg/1 to 1000 mg/1. Experiment II confirmed the lowest toxic whole-log concentration. Experiment III divided the lowest toxic whole-log concentration into tenths of a log and Experiment IV confirmed the lowest toxic one-tenth of a log concentration. In each of the tests, 3 adult hydra were placed in 9 ml of hydra media containing 150 mg/1 of Amikacin sulfate (an anti-bacterial agent), and the appropriate concentration of the substance being evaluated. Every 24 hours, the hydra were placed in a new solution with the identical chemical composition of the solution used within the first trials. Amikacin sulfate was used for all testing of adult and "embryo" hydra, as well as with all of the controls.

To test "embryo" hydra, hundreds of adult *Hydra attenuata* were bathed in iodine to reduce the potential of bacterial contamination, rinsed, and kept in a glass jar, separate from the main culture, for 3 days. These adult hydra were then placed into 3 ml of 70 mosmol reaggregation media[10] (pH 7) which consisted of 0.29 g KCl, 0.97 g $CaCl_2$, 0.16 g $MgSO_4$, 1.94 g Na citrate, 0.73 g Na pyruvate, 3.00 g TES, and 0.10 g phenol red dissolved in 1 liter distilled water. 150 mg/1 of Amikacin sulfate was added. After 30 minutes, the hydra were removed from the reaggregation media and were dissociated into their component cells and tissue fragments by repeated pipetting. After this mixture of cells was centrifuged to form a cell mass, the supernatant was removed and the mass was resuspended. This suspension was drawn into ID 0.58 mm polyethylene tubing which was then sealed with wax. The tubing was centrifuged to manipulate the hydra cells into a long, thin pellet. This pellet of cells was slowly ejected into sterilized, covered glass dishes containing 9 ml of 70 mosmol reaggregation media, Amikacin sulfate, and specific concentrations of the substance being tested. Because the pellets were formed in a high molarity reaggregation media which was not suitable for adult hydra, the molarity was reduced to 35 mosmol and 17.5 mosmol at 4 and 18 hours, respectively. At 26 hours the pellets were transferred to hydra media, which was replaced with fresh media at 42 and 66 hours. The pH and the concentration of both the Amikacin sulfate and the substance being tested

remained constant through all the media changes.

During all experimentation, both the adults and "embryos" were incubated at 21°C and were observed at 4, 18, 26, 42, 66, and 90 hours of chemical exposure. Any abnormalities, as compared to the controls, were noted.

Results

Figure I displays the reaction of "embryo" *Hydra attenuata* to 2,4,5-T in Experiment I. Figure II is a summary of the identification of the lowest toxic concentration of 2,4,5-T for "embryo" *Hydra attenuata.*

After identifying the lowest toxic dose of a substance for both adult (A) *Hydra attenuata* and "embryo" (E) *Hydra attenuata,* a ratio of the adult concentration to the "embryo" concentration (A/E ratio) was calculated. Table I displays the lowest toxic concentrations of the test substances on adult and "embryo" Hydra, as well as the ratios calculated using these two figures. A small A/E ratio indicates that the substance disrupts

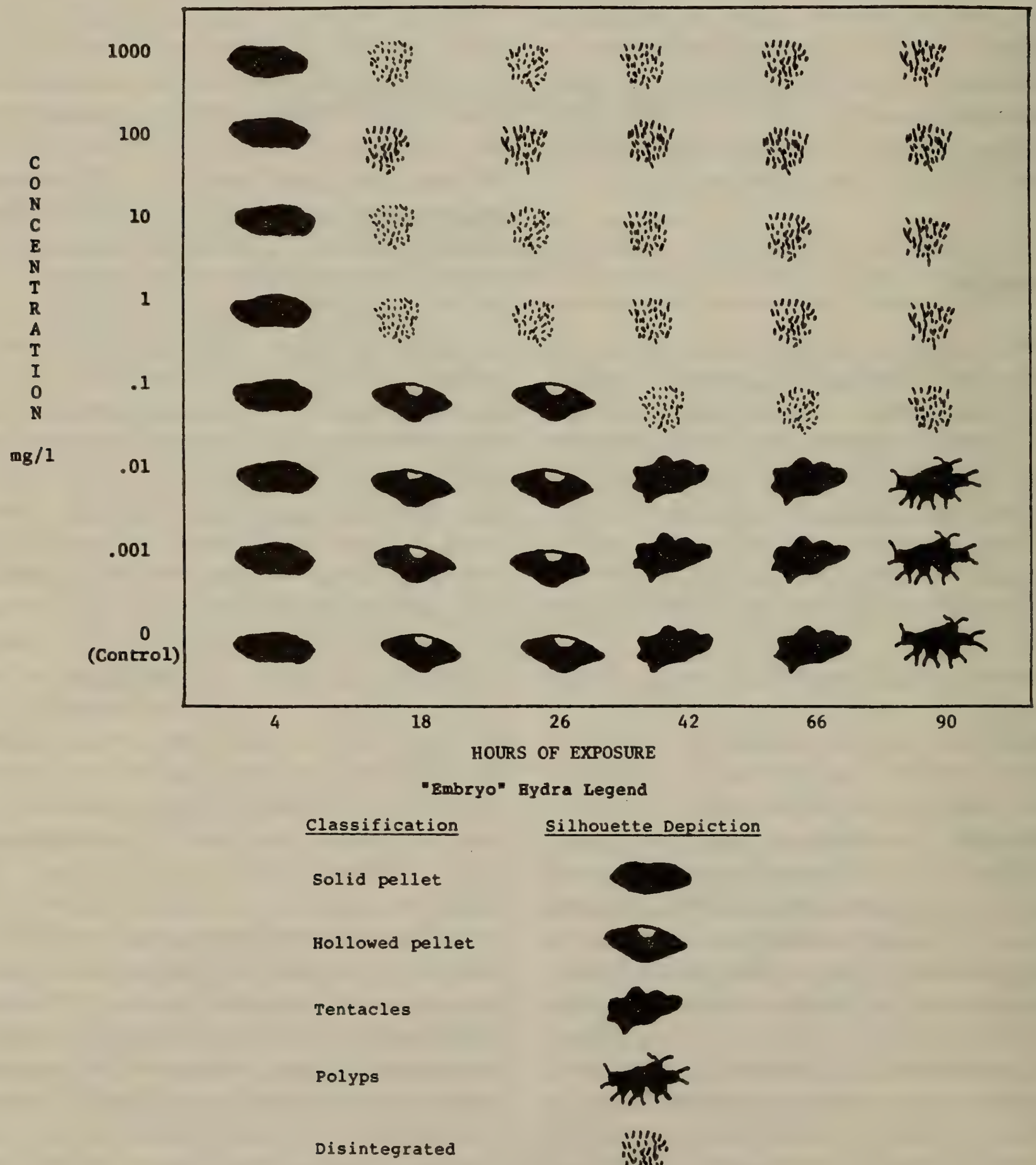

Fig. 1.

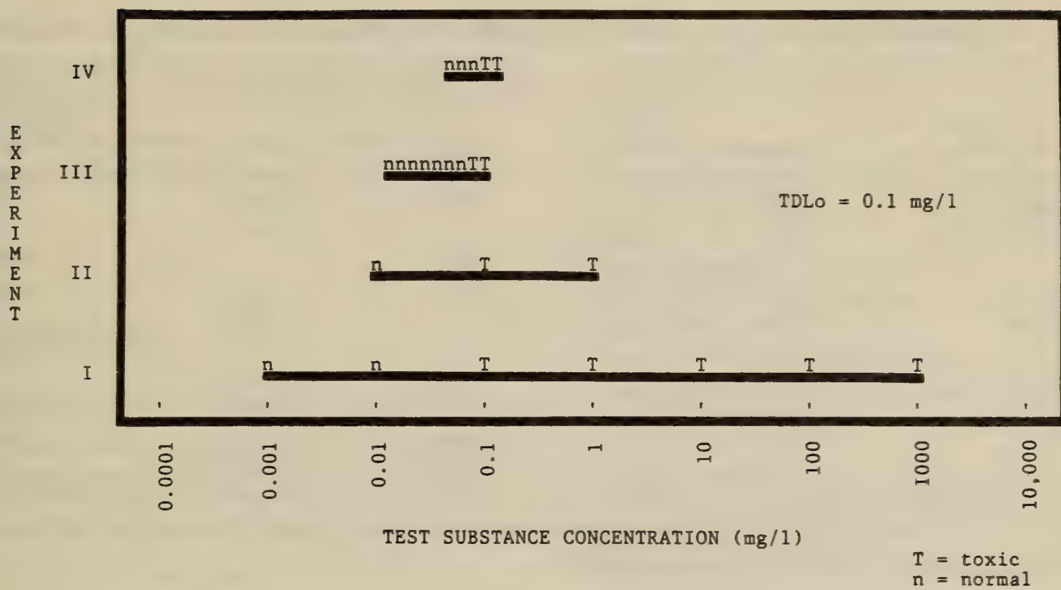

Fig. 2. Summary of experimental identification of lowest toxic concentration of 2,4,5-T for "Embryo" *Hydra attenuata*

development only at or near the concentration also toxic to the adult (a developmentally non-hazardous substance). A large A/E ratio indicates that the substance disrupts developmental events at a small fraction of the exposure toxic to adults (a teratogenic hazard). A rank order of a group of substances, beginning with the lowest A/E ratio and finishing with the highest A/E ratio, results in a substance list showing increasing teratogenic potential.

To validate this new rapid assay using *Hydra attenuata,* the A/E ratio for each of the substances evaluated in this research was compared to results of published rodent studies. Table II lists the lowest toxic concentrations, obtained from the *Registry of Toxic Effects of Chemical Substances,*[11] for both adult and embryo rodents, and the ratios calculated using these dosages.

Limitations

Though all experimentation was carefully controlled, the following limitations affected analysis of results:

1. The technique described has been found to be viable with only a specific hydra species.
2. The development of all experimental pellets must be verified and control pellets at all times because of the general tendency for some pellets not to be viable due to incorrect dissociation processes.
3. This hydra assay is capable of evaluating the toxicity of any compound except those containing copper since copper interferes with protein synthesis in hydra.

Table I.—Lowest Toxic Concentrations for Test Substances on Adult and "Embryo" Hydra (mg/l).

Chemical Tested	Adult	"Embryo"	Adult/"Embryo" ratio
Acetaminophen	100.0	—	—
Agent Orange	0.08	0.01	8.0
Carbon Tetrachloride	0.50	—	—
2,4-D	4.0	—	—
Formaldehyde	0.003	—	—
Lead Dioxide	1.0	—	—
Lithium Chloride	50.0	50.0	1.0
Salicylic Acid	7.0	400.0	0.018
2,4,5-T	0.80	0.10	0.86

TABLE II.—Published Lowest Toxic Concentrations for Test Substances in Utero and Adult Rodents (mg/kg).

Chemical Tested	Species—Route	Adult	Embryo	Adult/Embryo ratio
Acetaminophen	Rat—orl	2400	1500	1.6
Carbon Tetrachloride	Rat—orl		2000	
	Rabbit—ipr	478		0.24
2,4-D	Mouse—suc/orl	368	882	0.42
Formaldehyde	Mouse—ims		259	
	Rat—ivn	87		0.34
Lead dioxide	Guinea pig—ipr	220	—	—
Lithium Chloride	Mouse—ipr/orl	1165	320	3.64
Salicylic Acid	Rat—orl	1000	540	1.85
2,4,5-T	Mouse—orl	389	450	1.95

(For adults, the lethal dose for 50% of the entire experimental population was used. For embryos, the lowest dose of a substance to produce any toxic event was selected.)

4. Though cautious comparison was made with published rodent toxicity statistics, not all comparisons could be validated by published studies employing the same organism or the same method of chemical exposure.

Analysis

In comparison to published results of in utero and adult rodent toxicity studies, the following general characteristics of the *Hydra attenuata* assay have been confirmed and statistically verified by the Spearman's Correlation Coefficient, with an alpha level equal to 0.05:

1. Concentrations of chemicals toxic to adult hydra are predictive to the magnitude of toxicity for adult rodents but are not predictive of the magnitude of toxicity for rodent embryos.
2. Concentrations of chemicals toxic to "embryo" hydra are predictive of the magnitude of toxicity for rodent embryos but are not predictive of the magnitude of toxicity for adult rodents.
3. A ratio (adult/"embryo") of hydra toxic chemical concentrations is predictive of a ratio (adult/embryo) of rodent toxic chemical concentrations.
4. Concentrations of chemicals toxic to adult hydra are not predictive of the magnitude of toxicity for "embryo" hydra nor are adult rodents predictive of the magnitude of toxicity for embryo rodents.

Conclusion

Through the previous analysis of the results and verification with the Spearman Correlation Coefficient, it may be noted that the *Hydra attenuata* assay, which was designed, developed, and validated through this research, is a viable screening technique for the rapid identification of chemicals which could be potentially dangerous to developing organisms.

Calculation of the adult/"embryo" hydra ratio by this system quickly and accurately reflects conclusions possible for complex animal studies since it predicts the magnitude of a chemical's toxicity to developing organisms. The great majority of substances are no more hazardous to embryos than to adults, but the *Hydra attenuata* assay quantitatively identifies the chemicals with the greatest possibility of disrupting developmental processes. This allows for rapid separation of developmentally nonhazardous substances from potential teratogenic hazards, which would mandate further testing before dissemination.

The extensive experimentation and the careful use of controls within this project allow acceptance of the hypothesis that the *Hy-*

dra attenuata assay can be used as an accurate screening technique for the identification of chemicals which could be potentially dangerous to an organism if such chemicals were improperly distributed within the environment.

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Seagrass Leaves: An Alternative to Commercial Fertilizers on Coastal Poor Soils in Tropical Islands

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ABSTRACT

In view of the increasing costs of commercial fertilizers and poor coastal soil conditions of tropical islands, a study to determine the value of highly productive seagrass leaves (*Thalassia testudinum*) (Konig, 1805) as a nutrient source for cultures of corn plants was conducted. The experiments consisted of growing the plants from seeds placed in containers containing gravel, as a control medium, and in containers with different proportions of dried, ground seagrass leaves mixed with gravel. Plants grown in gravel alone were used to simulate soils with little or no organic matter content. In addition the same plants were grown on sterile soil with or without seagrass litter as fertilizer. All plants grown with seagrass litter grew significantly higher and faster than control plants and presented no signs of chlarosis. Experimental plants were also observed to grow relatively healthier than control plants. It was also determined that the tropical seagrass, *Thalassia testudinum,* grows relatively fast (23–25 cm/15 days), suggesting that it could be harvested in the future for growing such products on underdeveloped islands with inadequate coastal soils. Seagrass leaves are rich in nutrients (Vicente, 1982), help preserve soil humidity, and calcareous epiphytes on them help to stabilize the pH of the soil by acting as buffers.

Introduction

Seagrass meadows, mainly composed of turtle grass (*Thalassia testudinum*) are abundant on the South, East, West and North coasts of Puerto Rico. They also provide nursery, mating and feeding grounds for a wide variety of commercial fishes, mollusc, shrimp and other crustaceans. Seagrass meadows have a high leaf production, and these leaves are high in essential nutrients. In view of poor soil conditions near the Puerto Rican coasts (mainly sandy soils), a study was conducted to determine the potential use of Thalassia leaves as a nutrient source for poor soils for the growth of vegetables. In addition, the growth rate of Thalassia leaves was determined on natural meadows on the North, South, East and West coasts of the island of Puerto Rico (see Figure 1). The results of this study indicate that dried, grounded Thalassia leaves are good source of nutrients and organic matter for vegetables grown in gravel (simulating a poor soil), and a good fertilizer for these

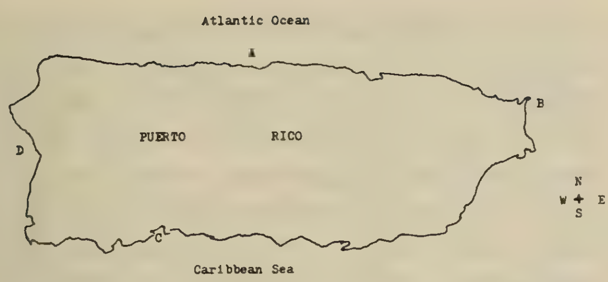

Fig. 1.
A-La cueva del Indio station
B-Las Croabas station
C-Guayanilla Bay station
D-Punta Arenas station

plants grown in sterile soil. In addition, small, calcareous epiphytes on Thalassia leaves, still present on the processed leaves, stabilize the pH of the soil.

Materials and Methods

Experiment I. Thalassia leaves as an organic source for corn plants grown in gravel.

Thalassia leaves were collected in Guayanilla Bay (South coast of Puerto Rico). A total of 21 pounds were obtained. The leaves were dried for seven days. 75 containers were labeled as follows: 15 containers V; 15 containers W; 15 containers X; 15 containers Y; and 15 containers Z. The necessary amount of gravel was then obtained. Different concentrations of dried, ground, Thalassia leaves with gravel were prepared. Concentration V contained 100% gravel as the control; W contained 20% Thalassia fertilizer; X contained 40% of the fertilizer; Y concentration contained 60% of fertilizer; Z contained 80% of the fertilizer. Three seeds of each species of plants were planted in each container and 200 ml of water were added. The plants were measured every two days after germination occurred, and the results were tabulated (see Figure 2).

Experiment II. The potential of seagrass leaves as a liquid fertilizer for corn plants grown in sterile soil.

Seventy-five containers were filled with sterile soil, as in experiment I. Daily, 200 ml of water were added. Every two days, liquid fertilizer* prepared from Thalassia was added, the plants measured, and the results were tabulated. The mean and standard deviations were determined for each of the above (see Figure 3).

Experiment III. The growth of corn in different concentrations of Thalassia leaves with sterile soil.

The containers were filled with the previous concentrations (V,W,X,Y,Z) of seagrass leaves substituting sterile soil for gravel. Corn seeds were planted in the containers, 200 ml of water were added, and the plants were measured every two days. Results were

Day	V	W	X	Y	Z
3	3 cm.	3 cm.	4 cm.	5 cm.	8 cm.
5	5 cm.	5 cm.	7 cm.	9 cm.	12 cm.
7	7 cm.	7 cm.	9 cm.	10 cm.	15 cm.
9	9 cm.	9 cm.	12 cm.	14 cm.	18 cm.
11	11 cm.	12 cm.	17 cm.	18 cm.	21 cm.
13	13 cm.	14 cm.	21 cm.	22 cm.	25 cm.
15	16 cm.	17 cm.	24 cm.	24 cm.	29 cm.
17	18 cm.	19 cm.	27 cm.	27 cm.	32 cm.
19	25 cm.	21 cm.	33 cm.	34 cm.	41 cm.
21	30 cm.	32 cm.	41 cm.	43 cm.	53 cm.

Fig. 2. Experiment I: Growth rate of plants
V-Control
W-20% fertilizer
X-40% fertilizer
Y-60% fertilizer
Z-80% fertilizer

Comparison	t value	p
V-W	9.43	.001
V-X	14.42	.001
V-Y	42.66	.001
V-Z	51.27	.001
W-X	8.91	.001
W-Y	31.55	.001
X-Y	8.61	.001
X-Z	18.59	.001
Y-Z	40.91	.001

df=8

Fig. 3. Experiment II: Corn planted in sterile soil and liquid fertilizer under four experimental conditions

*The liquid fertilizer was prepared adding 200 ml. by volume of ground Thalassia to 1000 ml. of distilled water.

Comparison	t value	p
V-W	7.27	.001
V-X	1.04	ns
V-Y	24.93	.001
V-Z	28.87	.001
W-X	0.70	ns
W-Y	24.00	.001
W-Z	25.80	.001
X-Y	0.32	ns
X-Z	0.78	ns
Y-Z	7.22	.001

df=8

Fig. 4. Experiment III: Corn planted in sterile soil and Thalassia under four experimental conditions

tabulated, and the mean and standard deviation were determined (see Figure 4).

Experiment IV: Growth rate of *Thalassia testudinum* in Puerto Rico.

Four stations were selected: La Cueva del Indio (North coast), Las Croabas (East coast), Guayanilla Bay (South coast), and Punta Arenas (West coast). A quadrant frame (1 ft. × 1 ft.) was placed in each station. Each leaf within the quadrant was labeled according to the method of Zieman (Zieman 1975). Every 15 days the leaves were cropped and measured. The experiment was repeated for 3 months and all results were tabulated. Final average results are shown in Figure 5.

Station A	Station B	Station C	Station D
25 cm.*	23 cm.	24 cm.	25 cm.

*per 15 days

Fig. 5. Experiment IV: Growth rate of Thalassia testudinum

Results

After the seeds had been planted and plant development under the specified conditions (gravel, sterile soil and liquid fertilizer), it can be seen that average plant growth increases in proportion to the fertilizer concentration. In I,V concentration (gravel control) plants had a growing average of 30 cm. In the I,W concentration which had 20% Thalassia fertilizer, the growing average was 32 cm. In I,X, which contained 40% of the fertilizer, there was a 41 cm. average. The I,Y concentration, 60% of fertilizer, averaged 45 cm. The I,Z concentration plants had a growing average of 53 cm. (notice the fact that this concentration continued 80% fertilizer, but it did not affect the plant's metabolism). The plants seeded in sterile soil with different concentrations of Thalassia fertilizer grew faster; in the II,V concentration (the control), plants grew an average of 34 cm. In II,W concentration, with 20% Thalassia fertilizer, plants averaged 37 cm. In II,X with 40% fertilizer, plants grew an average of 45 cm. In II,Y with 60% Thalassia, plants had a growing average of 49 cm; and in II,Z concentration which contains 80% fertilizer, a 57 cm. average was achieved. In the III,V concentration (control) a 31 cm. average was obtained, in the III,W where the Thalassia fertilizer was used in liquid form (200 ml) there was 36 cm. grow. The III,X, with 400 ml. added daily, obtained a growing average of 44 cm. A 600 ml. of fertilizer were added to the concentration III,Y each day, and a 49 cm. average was obtained. In III,Z, to which 800 ml. of fertilizer were added, a growing average of 59 cm. was achieved (figure 6). As shown, the fertilizer in liquid form was more effective than the other feed forms.

Conclusions

After analyzing the results, it was found that Thalassia leaves grow relatively fast (21–25 cms./15 days), suggesting that it could be harvested frequently. The rhizomes have stored energy in the starch which probably accounts for this fast growth. Dried, ground leaves of *Thalassia testudinum* proved to be an effective fertilizer for cultures for container vegetables grown in sterile soils. Dried Thalassia leaves are rich in essential nutrients and minerals for plant growth; appropriate quantities of magnesium, present in Thalassia

Condition	Mean
I, V	22.4
I, W	28.9
I, X	35.8
I, Y	33.6
I, Z	43.4
II, V	30.2
II, W	35.2
II, X	42.6
II, Y	49.4
II, Z	58.4
III, V	30.2
III, W	35.0
III, X	44.9
III, Y	49.4
III, Z	55.9

Fig. 6. Means of corn growth in different soil conditions
A-Gravel + Thalassia, Experiment I
B-Sterile Soil + Liquid fertilizer, Experiment II
C-Sterile Soil + Thalassia, Experiment III

Comparison	Condition	t value	p
VA-VB	control	2.75	.05
VA-VC	control	2.73	.05
VB-VC'	control	0.00	ns
WA-WB	20%	4.17	.01
WA-WC	20%	4.06	.01
WB-WC	20%	0.83	ns
XA-XB	40%	3.36	.01
XA-XC	40%	0.64	ns
XB-XC	40%	0.16	ns
YA-YB	60%	6.81	.001
YA-YC	60%	9.94	.001
YB-YC	60%	0.00	ns
ZA-ZB	80%	1.43	ns
ZA-ZC	80%	1.19	ns
ZB-ZC	80%	2.94	.02

df=8

Fig. 7. Corn planted in three different soils with equal concentrations of fertilizer
A-Gravel + Thalassia, Experiment I
B-Sterile Soil + Liquid fertilizer, Experiment II
C-Sterile Soil + Thalassia, Experiment III

leaves are important for chlorophyll synthesis (Vicente, 1982). Thalassia leaves also proved to be a source of valuable organic matter since plants grew healthy and significantly more (p .05) than controls (see figure 7). Stabilization of soil pH was observed when Thalassia leaves are used. This is most likely due to carbonates of encrusting calcareaus (CaCO3) algae present on Thalassia leaves. On coastal poor soils, seagrass leaves which can be harvested or collected on the shore can serve as fertilizer or as an organic source for the growth of at least some truck products. In view of increasing costs of commercial fertilizers, seagrass leaves may be a valuable alternative.

TAXONIMICAL CLASSIFICATION OF THE SEAGRASS:
Order: Hidrocharitales
Family: Hidrocharitaceae
Genus: Thalassia
Species: testudinum
Filum: Espermatofite

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Argus

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ABSTRACT

Breaking technological barriers, Argus is an exceptionally versatile optical analyzer. This project is designed so that any corporation can increase and ensure efficiency in quality control and inventory control by the implementation of this low-cost inspection system on their production lines. This represents a significant advance because the system can eliminate the production and employment of defective components. This will conserve millions of dollars expended on recalls and discarded inventory.

Argus has been designed to analyze an object electromagnetically and provide immediate information about its type and quality. Then, this data is compared with previous data to enable the system to watch for trending. Therefore, Argus will predict when machinery will begin producing defective components because of tool wear. If the parameters should exceed their limits, Argus immediately will commence shut-down procedure of machinery to prohibit the production of unuseable parts.

Argus is an optical instrument consisting of an inexpensive dynamic memory which is light sensitive when the protective cover is removed because of the photoelectric effect. The imager is interfaced with a microcomputer which also is interfaced with the production lines. It is possible to interface Argus with the corporation's mainframe computer system and provide instantaneous inventory information as well as quality control checks.

This project will supply the need for a low-cost inspection system. Also, the system can be modified easily for use in many other applications (e.g., a night vision system for surveillance and security, fingerprint and signature verification, robot vision, and missile guidance system).

Problem:

The objective of this project was to design a solid-state imager so that any corporation could increase and ensure efficiency in quality control, as well as inventory control, by the implementation of a low-cost inspection system on their production lines. The system then should eliminate the production and employment of defective components. This could save a corporation millions of dollars expended on recalls and discarded inventory.

Hypothesis:

An optical instrument should be designed to analyze an object and provide immediate information about its type and quality. Then, the information could be compared with previous data to enable the system to watch for trending. Therefore, the system could predict when machinery would begin producing defective components because of tool wear. However, if the parameters should exceed their limits before the tooling has been adjusted,

immediately the system should begin shutdown of the production line to prohibit the production of unuseable items.

Research:

An optical instrument is sensitive to light and, since light is a form of radiation, research of radiation was necessary.

After completing the research necessary to understand electromagnetic waves, the design of the solid-state imager was begun. The imager must focus the image on many small photoelectric devices in an array. Then the array should change a voltage in response to a change in incident light intensity. One way of doing this would be to use a vidicon tube similar to those in television cameras. However, after research, the practicality of the vidicon tubes was questionable because of their power consumption and the lack of compatability with computers. During the research of the photoelectric effect, the idea of using a dynamic RAM (Random Access Memory) was conceived. If this theory could be proven to be correct, the use of a dynamic RAM would be excellent because of low power consumption and computer compatability.

The memory known as a dynamic RAM is an integrated circuit which stores its data as a charge instead of in a flip-flop like a static memory, and the electrical charge should be able to be discharged by the exposure to light. The rate at which the electrons are released should also be related to the intensity of the light. This should work because of the photoelectric effect, since under certain conditions the current flowing in an electrical circuit may be affected by the action of light falling on some suitably prepared part of the circuit.

To test this theory, the protective cover would have to be removed from a dynamic memory to expose the inside electronic die. The cells used to hold data on this die should be sensitive to light. Therefore, if all logic ones are written into the memory exposed to light, the locations getting strong light should turn to logic zeros. So, if an image if focused on the IC surface using an inexpensive lens system, light should be distinguished from dark areas by simply reading the contents of the chip. Another feature of this approach is that infrared light should also be detected; thus, if a dark area is illuminated with infrared light, one can see in the dark.

Since dynamic memories are ICs that store data, the information is being stored internally as a charge on a tiny capacitor. Capacitors eventually bleed off their charges and the time it takes depends on their size and leakage. In this case, the capacitor is so tiny that it takes a mere 2-milliseconds to lose the charge.

After testing the dynamic RAM, it was determined that light striking the cells serves to accelerate the bleed off. Because each cell has only two states (on or off), only black or white can be detected. The important thing is to try to sharply focus the image on the die area of the chip. Two months of research and testing of various designs resulted in the design of Argus.

The newly designed imager, Argus*, is an optical instrument consisting of an inexpensive dynamic memory which has been exposed to light. Since the dynamic memory has to be operated at high speeds, it was necessary to interface it with a microcomputer. After designing and constructing an interface circuitry so that the microcomputer could read the optic imager (dynamic RAM), a program had to be developed that could read the imager in less than 2-milliseconds. Programs had to be written in Assembly Language (Machine Language) because the more common language known as BASIC is not fast enough. BASIC is a fine general-purpose tool, but it has its limitations; Assembly Language performs much faster. In Assembly Language the programmer is speaking directly to the computer. Actually, the Assembly Language is the only language the computer understands. When a programmer writes in BASIC, the programs have to be interpreted by the computer before the instruction can be performed; therefore, BASIC cannot be as fast as Assembly Language. Therefore, the most

*In Greek Mythology, Argus was the name of a hundred-eyed monster; the name denotes a watchful guardian.

crucial parts of the program were written in Assembly Language and then called by the SYS (SYSTEM) command in BASIC.

It required four months to learn Assembly Language to write the programs. There are 56 instructions (commands) available in 6502 machine language. Most versions of BASIC have about 50 commands. Some BASIC instructions are rarely used by the majority of programmers: USR, END, SGN, TAN, LET, etc. Some, such as END and LET, contribute nothing to a program and seem to have remained highly specialized. There are surplus commands in computer languages just as there are surplus words in English. For example, people don't often say "culpability." They usually say "guilt." The message is understood without using the entire dictionary. The simple, common words can do the job.

Assembly Language is the same as any other language in this respect. There are approximately 20 instructions used heavily. The 36 remaining ones are used much less often. Assembly Language, like BASIC, offers many ways to accomplish a given job. Some programming solutions, of course, are better than others, but the main thing is to get the job done.

The best way to approach the "instruction set" might be to break it down into the following six categories which group the instructions according to their functions: 1. The Transporters; 2. The Arithmetic Group; 3. The Decisionmakers; 4. The Loop Group; 5. The Subroutine and Jump Group; and 6. The Debuggers.

One of the disadvantages of using Assembly Language is that a completely different instruction set is used, and the programming usually is done in the hexadecimal system, which is in groups of 16, rather than the decimal system, which is in groups of 10.

After the programs in Assembly Language had been written to obtain the necessary speed, the circuitry was constructed to interface the microcomputer with the imager. In order to demonstrate the imager's capabilities, a model production line was designed and constructed also. It took two months to design and construct the imager and the model production line. The model assembly line incorporated a method of separating defective items from those meeting specifications upon command from the microcomputer.

Upon the completion of Argus, it was not operating as planned. Another month was required to isolate and remove the imperfections in the system. Several flaws were found in the focusing of the imager. Moreover, the logical address of the cell did not correspond with the physical placement of the cells on the sensing array. In order to take care of this problem, only every other column was read across. There were also several errors found in the program dealing with the time delay between the writing and the reading of the light sensitive cell.

Presently Argus is capable of seeing in black and white. Experimentation with the possibility of having Argus see in color was planned. Since the design and construction of Argus required more time than expected, there was not sufficient time to conduct research in this area.

Conclusion:

A vision system such as Argus will supply the need for a low-cost inspection system.

An inexpensive dynamic memory utilized as an optic imager will provide for the inexpensive installation of an inspection system that will conserve millions of dollars expended on recalls and the return of defective products by consumers. Since the imager can

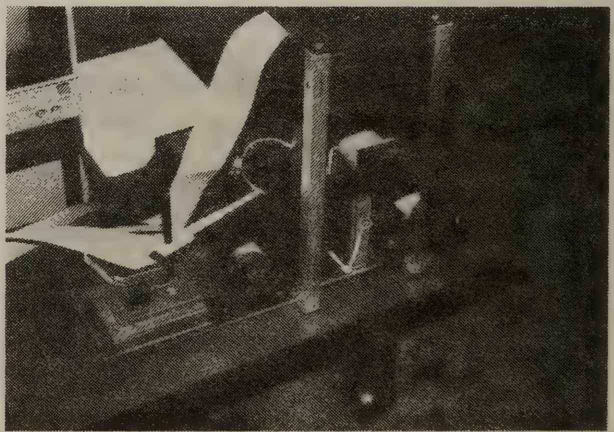

Fig. 1. The Imaging System (top); the model production line, the conveyor system, (bottom).

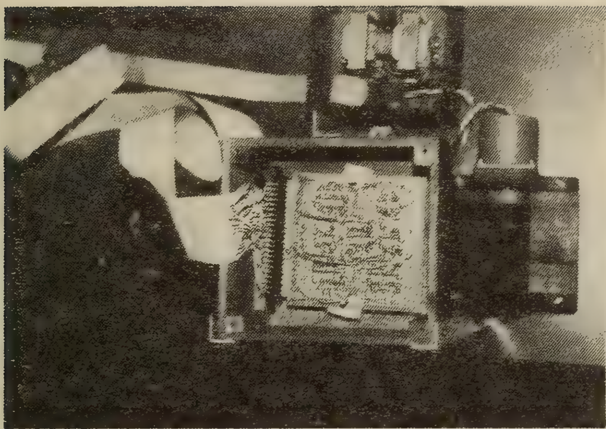

Fig. 2. The Imaging System with the cover removed, exposing the back of the imaging board.

Fig. 3. The front side of the imaging board. (Note: The chip in the center is the dynamic RAM which has been made light sensitive by the removal of its opaque cover.

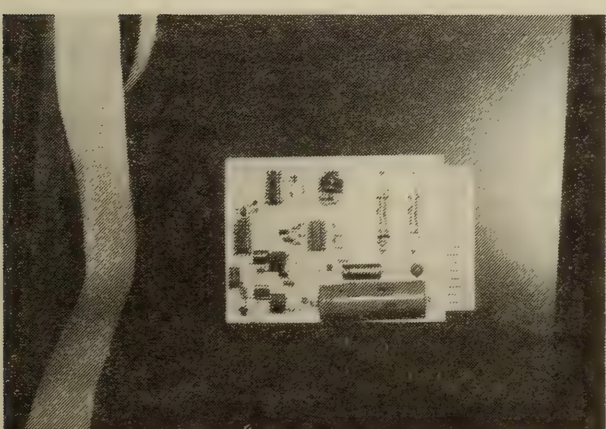

Fig. 4. The interface board—this board interfaces the microcomputer to the production line.

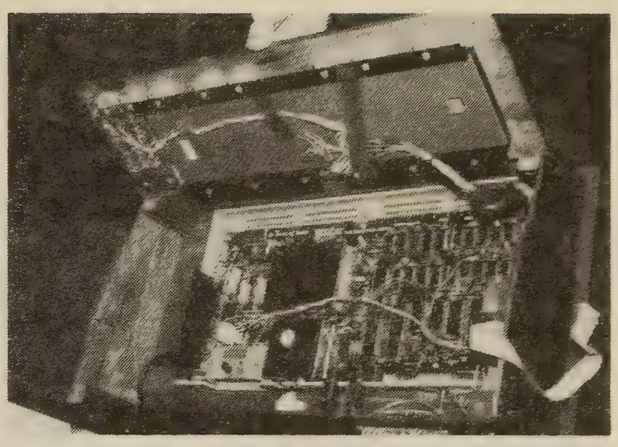

Fig. 5. The home computer with its many modifications.

be used to watch for tool wear, money can be saved also through the prevention of the production of defective components. Because of the utilization of an ordinary computer's dynamic RAM, this vision system will cost as little as $50. Obviously, the prevention of waste in production will pay for the system soon after, if not immediately upon installation.

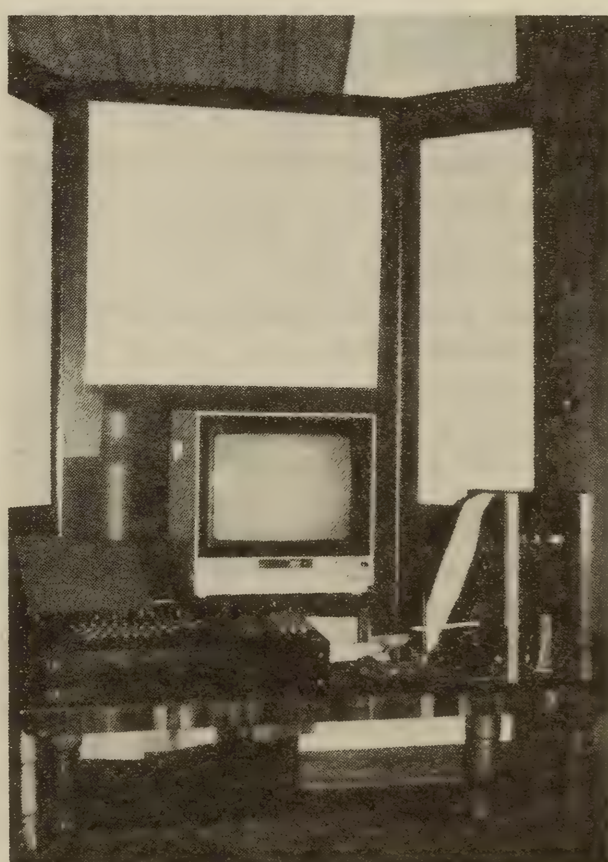

Fig. 6. The completed project entitled *ARGUS*.

For inventory control as well as quality checks, it is possible to interface the system with a corporation's mainframe computer to provide instantaneous information.

The system can be modified for use in many applications (e.g., a night vision system for surveillance and security, fingerprint and signature verification, robot vision, character recognition, time-lapse motion studies, measuration, telescope tracking system for astronomers, barcode reading, and in a guidance system for missiles).

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The Allelopathic Aspects of Melilotus Alba Through Coumarin

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ABSTRACT

White sweet clover is capable of producing sharp reductions in growth and germination of competitive seeds. The majority, if not all, of these effects are caused by the chemical coumarin which the clover plant produces and releases into the soil in excessive amounts to aid the clover plant by inhibiting enzymes necessary early in germination.

Introduction

Numerous plants found in the world today have been discovered to exhibit the ability to influence the well being of other plants in the surrounding vicinity. A complete scientific division, called allelopathy, has been created to study the abilities of these plants to generate harmful effects on another plant through the production of chemical substances that the plant releases into the environment.[7] One plant that is suspected of utilizing an allelopathic capability is white sweet clover, *Melilotus alba*. This biennial plant is commonly used on farm land after numerous successive years of planting in order to replenish minerals and organic material to the depleted soil. If white sweet clover does exhibit allelopathic abilities, these traits may also be an agricultural asset of the plant.

Experiment

If white sweet clover does actually have allelopathic abilities, it would to some extent affect the growth and germination of other plants. To investigate this, two flats were prepared by dividing each into seven adjacent sections. In one flat, sections were divided by a barrier of stained wood to prevent water diffusion, and in the other no barriers were placed. Clover seeds were planted in four sections of each flat and were allowed to mature thirty days before ninety dandelion seeds were introduced into the three remaining sections between the clover. The number of germinated seedlings and the growth of the plants, the distance between the stem's contact with the soil and the tip of the longest leaf, was recorded daily in the two experimental flats and a control group.

Also, several groups of white sweet clover were grown in flats for approximately four months. At this time the plant material and the soil were separated, and the ability of the soil to reduce the germination of dandelion seeds was tested. One hundred dandelion seeds were planted in a flat containing only soil from the sweet clover plants, and the number of germinated seedlings was counted daily for a period of eight weeks.

From research, one chemical was found to be fairly unique to the white sweet clover plant, and such uniqueness may be connected to the allelopathic effects. This compound, coumarin (Fig. 1), is a member of the organic functional group of lactones,[8] and is present in its pure form at high concentration in only three plants: a sweet grass, *Hierochloe odorata,* the tonka bean, *Dipteryx odorata,* and white sweet clover itself.

From the previous set of experiments, the compound influencing growth and germination of the dandelion plants would have to be present in the plants themselves and the soil. A method of extraction and detection was developed to determine if coumarin was one of the compounds present in both substances. Approximately 4 gm of white sweet clover plant material, 5 gm of soil where clover had been grown, 5 gm of soil not exposed to clover, and 5 gm of white sweet clover seed were independently ground in a mortar and then extracted with a saturated sodium sulfate solution for a period of 24 hours. The extract

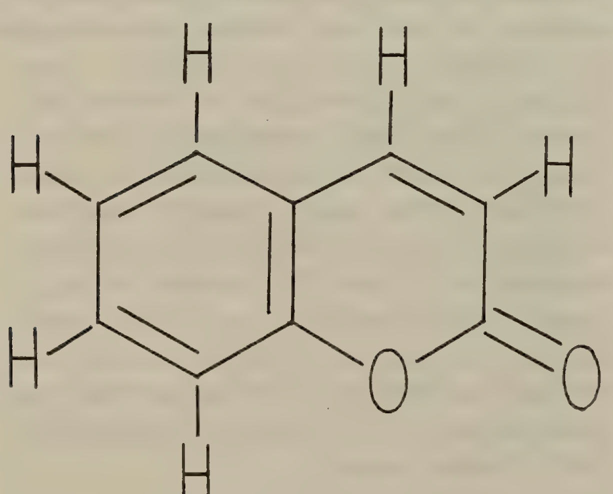

Fig. 1. Structural formula for coumarin. (1,2-Benzopyrone)

was then steam distilled, and the distillate extracted with chloroform since coumarin is volatile in steam[12] and very soluble in chloroform.[6] Compounds present in the extract were identified using thin layer chromatography with a layer of silica gel G, a solvent of hexane and ethyl acetate (5:2), and the chromatograms were developed by spraying them with 1% alcoholic potassium hydroxide, which resulted in a green fluorescence in ultraviolet light.[13]

Since coumarin was detected both in plant material and the soil, a quantity of synthetic coumarin was needed to determine if it was the cause of the allelopathic effects of sweet clover. The synthesis of coumarin was carried out using a variation of the Perkins reaction.[3] The melting point,[6] nuclear magnetic resonance spectrum,[11] and infrared spectrum[10] were used to test purity. The nuclear magnetic resonance spectrum showed a minute trace of possibly triethylamine a starting product.

The effect coumarin has on the germination of numerous seeds including dandelion, tall fescue grass, radish, corn, and white sweet clover itself was tested at varying concentrations, as well as the ability of such substances as amylase, sucrose, hydrogen sulfide, and gibberellic acid to reverse the effect of coumarin. One hundred seeds of each variety were placed in petri dishes containing 5 ml of courmarin solution, ranging in concentration from 5×10^{-3} to 10^{-12} molarity which corresponds to 570 mg to .0001 μg of coumarin per square meter. Similar procedures were used to attempt to reverse the effect of coumarin at the 570 mg/m^2 concentration. Dandelion, tall fescue grass, and corn seeds were also planted in soil contained in flats which were then exposed to concentrations of coumarin ranging from 5 gm to .1 mg/m^2 by applying one liter of water solution containing the proper amount of coumarin.

Results

The results obtained when dandelions were grown to next to sweet clover plants indicate sweet clover has the ability to reduce the growth

and germination of these plants some 30% and 23% from control, respectively. When dandelion seeds were germinated in the soil of white sweet clover, they exhibited an 84% reduction in germination for the first four weeks, though by the eighth week there was only a 42% reduction.

The outcome of the thin layer chromatography of both the extracts of white sweet clover plant material and the soil surrounding the plants indicated the presence of coumarin. Both chromatograms had bands of green fluorescence that had R_F values which matched fairly close to that of a control. Chromatograms of the extracts of white sweet clover seeds did not indicate an appreciable amount of coumarin, though an amount of o-coumaric acid was detected. Since o-coumaric acid is a precursor to coumarin in biosynthesis,[1] the amount present in the seed is probably later converted to coumarin.

Coumarin alone was found to be a potent inhibitor of germination. In dandelion, grass, and clover seeds the highest concentration of coumarin, 570 mg/m^2, when applied to the petri dish caused a 100% reduction in germination while corn and radish seeds showed a 51% and 86% reduction, respectively. In clover, corn, and radish the germination had risen to that of the control by the 11 mg/m^2 concentration and remained there for the remainder of the concentrations. On the other hand, the grass (Fig. 2) and dandelion seeds (Fig. 3) exhibit a pattern of high and low peaks as the concentration decreases, yet dan-

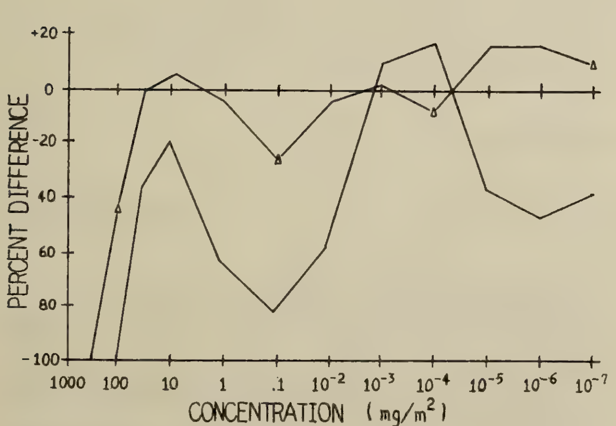

Fig. 2. Percent increase or decrease in germination from control according to concentration in tall fescue grass. –·– at 48 hours, –△– at 144 hours

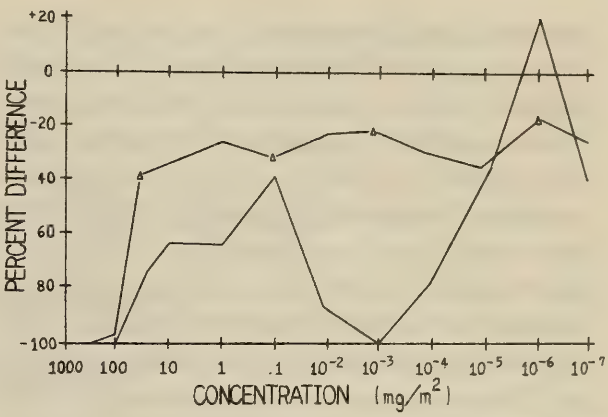

Fig. 3. Percent increase or decrease in germination from control according to concentration in dandelion. –·– at 72 hours, –△– at 144 hours

delion seeds never attained less than a 14% reduction in germination while grass at times surpassed that of the control. At 144 hours into germination, both seeds showed low peaks at approximately .1 mg and .1 μg/m^2. A similar pattern was observed in those that were germinated in soil, though the greatest reduction was 42% in the dandelion seeds.

Early in germination the same pattern also existed though the peaks were in slightly shifted positions and were more pronounced. The shift may be due to the possible metabolism of coumarin by the seed,[4] reducing the total amount present. At concentrations where reductions of germination exist, the majority of the seeds that do germinate do so at approximately 96 hours, and a lower percentage than the control germinated during the first 72 hours. When certain metabolites were used to attempt to reverse inhibition by coumarin, hydrogen sulfide, a proteinase enzyme activator,[14] and gibberellic acid, which activates α-amylase and numerous other enzymes,[9] increased the germination 24% and 41%, respectively, while amylase and sucrose both increased germination 9% from that of the highest concentration of coumarin.

Conclusion

White sweet clover exhibits a potent allelopathic ability to reduce germination of seeds and to some extent growth of plants. These actions are carried out through the compound

coumarin which is released into the soil where it has a lag period of approximately four weeks before it begins to decompose probably through microbial attack.[8] Apparently, the white sweet clover plant is able to release an excessive amount of coumarin into the surrounding soil, since even at a concentration of 5 gm per square meter, the amount of reduction in germination is far less than that created by the soil where white sweet clover had been growing. Since lactones are known to bond with sulfhydryl groups,[5] as well as the delay in germination when coumarin is present and the ability of hydrogen sulfide to reverse its actions, coumarin apparently inhibits sulfhydryl enzymes that are necessary during the first 72 hours of germination. Such enzymes include proteinase which activates β-amylase,[14] the first form of amylase active in the seed, or β-amylase itself since both are sulfhydryl enzymes.[5] Since coumarin is fairly selective toward the smaller seeds, having less ability to inhibit germination of large seeds such as corn, and does not remain in the soil at high concentration for an excessive amount of time, the use of white sweet clover as a deterrent to severe weed problems in agriculture could be a previously unforeseen advantage of this plant.

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A Three Year Study of Fetal Auditory Imprinting

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ABSTRACT

The study of learning in animals is an important and vital part of behavioral experiments. The question of fetal learning and specifically fetal auditory imprinting is an area open to extensive investigation. This research is designed to determine if chickens can be imprinted to sound, variable sound frequencies and the sound of specific natural predators during the embryonic stage and then respond to the specific sound upon hatching.

To establish positive auditory imprinting, each of three groups of fertile eggs were exposed to the sound of ratio static, a high frequency sound (3000 Hz), and a low frequency sound (250 Hz). Another group was incubated with no sound to serve as a control.

To measure the response, each chick was placed in a Y maze with various sounds projected at a given leg of the Y. The locomotor response of the chicks demonstrated that fetal imprinting did occur in each of the experimental groups.

In the third year of study, an attempt was made to imprint the chicken embryo to the sound of a specific natural predator. Five separate groups of fertile chicken eggs were used, four experimental and one control group. The first two groups were separately exposed during the embryonic stage to a mammalian predator, *Felis rufus* (bobcat), and *Buteo lineatus* (red-shouldered hawk) respectively. The third and fourth groups were exposed separately to combination sounds of each predator with the maternal sound.

Each chick demonstrated a positive imprinting response for the sound with which they were incubated by exhibiting a positive locomotor response when placed in a Y shaped maze.

The significance of fetal auditory stimulation and ultimate responses of the neonate is established by the results observed in this investigation. This type of perceptual learning observed in the fetus and neonate of lower animals indicates a need for additional investigation in the area of auditory stimulation during the fetal stage.

Introduction

Many experiments have established the validity of visual imprinting. Experimentation has shown that a group of newly hatched chicks will accept the first object seen as their mother. Is it possible to imprint the chick in the fetal stage? Of course the unhatched chick can not see, but what about auditory stimuli? The use of auditory stimuli is a comparatively new field of study and is a form of fetal imprinting. Fetal imprinting is the process of exposing a specific animal to a particular sound while in the embryonic stage of development.

The study of learning in animals is an important and vital part of behavioral experimentation. The question of fetal learning and specifically fetal auditory imprinting is an area open to extensive investigation. This research is designed to determine if chickens can be imprinted to sound, variable sound frequencies, and predator sounds during the embryonic stage and then respond to the specific sound after hatching. The significance of fetal auditory stimulation and ultimate response of the neonate is established by the results observed in these investigations.

Method and Discussion

In the first year of experimentation, one group of ten fertile chicken eggs (*Gallus gallus*) was incubated with the sound of radio static. Another group of ten eggs was incubated with no sound as the control. After hatching, each group of chicks was tested three times a day for their sound preference by exposing them to the radio sound for five minutes in a "Y" shaped maze, with the simultaneous choice of the radio sound, peeping chicken sound and no sound projected at a given leg of the "Y". In the experimental group exposed to the radio sound, the ratio of preference of radio sound to no sound was 70:30. When given a choice of peeping to no sound the majority chose no sound 20:80; and peeping to radio sound 30:70. The ratio of responses in the control group with radio to no sound was 50:50; peeping to no sound 30:70; and peeping to radio sound, 50:50. Those chicks incubated to the radio sound demonstrated a positive locomotor response to that sound as a neonate.

In the second year of experimentation, in order to establish positive auditory imprinting, three separate groups of fertile chicken eggs were exposed to either a high frequency sound (3000 Hz), a low frequency sound (250 Hz), or no sound, as the control group. After hatching, the chicks were tested for their sound preference by exposing them to the specific sound frequency in a "Y" shaped maze. To measure each response, each chick was placed in a "Y" shaped maze with the various sound frequencies projected simultaneously from a given leg of the "Y". The locomotor response of the chick demonstrated that fetal auditory imprinting did occur in each of the experimental groups. The group exposed to 3000 Hz responded positively to that high frequency. The group exposed to 250 Hz responded positively to that low frequency. The control group, when given a choice of low frequency or no sound, preferred 250 Hz. They avoided 3000 Hz. In the experimental group exposed to 3000 Hz, the ratio preference was 250 Hz or 3000 Hz responded 10:90; no sound or 3000 Hz responded 20:80; and no sound to 250 Hz, 20:80. In the group exposed to 250 Hz, the ratio of preference was 250 Hz or 3000 Hz responded 60:40; no sound or 3000 Hz responded 100:0. In the control group incubated with no sound, the ratio of preference was 250 Hz or 3000 Hz, responded 90:10; no sound or 3000 Hz responded 80:20 and no sound or 250 Hz responded 30:70.

In a spectrum analysis an oscilliscope was used to compare the sound waves of the following sounds: 3000 Hz, 250 Hz, maternal vocalization, the vocalization of neonate chicks exposed to 3000 Hz, and the vocalization of neonate chicks exposed to 250 Hz. It was determined that the low frequency sound correlated more closely with the maternal sound of the species than did the other sounds. It was also determined that the low frequency sound correlated with the maternal sound of the species. It was also determined that there was no correlation of the vocal frequency of the neonates and the specific sound frequency to which they were exposed during incubation. The fact that the fetal group exposed to the high frequency was the only group that indicated preference to that high frequency, demonstrates positive embryonic stimulation and response.

In extending this research, an attempt was made to imprint the chick embryo to the sound of a specific natural predator. Five separate groups of fertile chicken eggs were used, four experimental and one control group. The first group was exposed to the sound of a mammalian predator, *Felis rufus,* also known as the bobcat. The second experimental group

was incubated with the sound of an avian predator, *Buteo lineatus,* also known as the red-shouldered hawk. The third group had equal exposure to *Felis rufus* and the maternal hen vocalization, and the fourth experimental group had equal exposure to *Buteo lineatus* and the maternal hen vocalization. The fifth group was incubated without sound as the control group.

After hatching, each chick was tested for the sound preference by exposing it to combinations of specific sounds in a "Y" shaped maze. Each chick was placed in the center of the maze with the various sounds projected at a given leg of the "Y". The neonates that were imprinted to the *Felis rufus* (bobcat) sound responded with a positive locomotor preference at the given leg of the maze. It was found that chicks incubated with the bobcat sound were at ease while it was being played, while the other groups were very timid and scared. The chicks incubated with the bobcat sound were tested with three different sound combinations and responded as follows: When given a choice of bobcat, hawk and no sound, 7:0:1; when given a choice of bobcat, chicken and no sound, 1:5:2; and when given a choice of chicken, hawk and no sound, 5:1:2.

The second group of chicks incubated with the hawk sound were given the choice of bobcat, hawk and no sound in which they responded 1:5:2; bobcat, chicken and no sound, 0:6:2; and finally given the choice of the chicken, hawk and no sound, 5:3:0.

The third experimental group of chicks was incubated with an equal combination of the bobcat and the chicken sound. They were given the choice of bobcat, hawk and no sound and responded 8:0:0; bobcat, chicken and no sound, 3:5:0; and then the choice of chicken, hawk and no sound, 8:0:0. These chicks demonstrated that they were not afraid of the bobcat sound.

The fourth group of chicks was incubated with an equal combination of the chicken and hawk sound. When given the choice of the bobcat, hawk and no sound, 0:8:0; bobcat, chicken and no sound, 0:8:0, and chicken, hawk and no sound, 6:2:0. In this experiment it was found that the chicks seemed to be more confused and very slow in reacting to the sounds.

The fifth group was not incubated with a specific sound and therefore was used as a control group. The control group was used to demonstrate the natural responses to the specific sounds. Given the choice of bobcat, hawk and no sound, they responded 0:2:6; bobcat, chicken and no sound, 0:7:1. These chicks were very sharp and alert, but were very calm and easy going.

The attempt was made to use the three different sounds at the same time, but the chicks seemed unable to distinguish between them. They became confused and therefore remained in the middle of the maze chirping.

Summary

A chicken embryo exposed to a specific sound during the incubation period will be attracted to that specific sound as a hatchling. This project demonstrates that a chicken in the embryonic stage of development can be imprinted to show a preference for an external auditory stimuli to which it was exposed as an embryo. Three types of sound stimuli were introduced in this study, each supporting the theory that pre-natal auditory learning does occur.

Conclusion

In conclusion, these experiments demonstrate that a chick embryo incubated with a specific sound will be attracted to that sound as a neonate. The chicks not imprinted to a sound will respond to the sound frequency most closely resembling the mature species maternal vocalization. The chicks imprinted to specific predator sounds will be attracted to that sound as a neonate. The significance of fetal auditory stimulation and ultimate responses of the neonate is established by the results observed in this investigation. This type of perceptual learning observed in the fetus and neonate of lower animals indicates a need for additional investigation in the area of auditory stimulation during the fetal stage.

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8. Jackson State University, Statistical Analysis

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Transitional Location and Laminar Extension in a Heated Boundary Layer

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ABSTRACT

Reducing the drag on an object can play a major role in decreasing the amount of energy required to propel it through its medium. The key in reducing drag on a submerged streamlined body lies in studying and manipulating the boundary layer, which is the microscopic layer of water that surrounds a body. The theory behind the heated boundary layer method of drag reduction lies in extending laminar flow, thus also reducing turbulent flow. Because laminar flow creates far less drag on a body than does turbulent flow, the drag should therefore be reduced.

In order to test this theory a streamlined aluminum body was constructed and tested in a home built open-jet water tunnel. Water in the tunnel was propelled at variable speeds of 2–8.8 ft/sec by a home built pump. The water was channeled into an octagonal observation box where the body was tested.

Tests showed that the heated boundary layer method of drag reduction was effective in reducing drag in various temperature differentials and at different Reynolds numbers.

Introduction

This ongoing project concerns itself with reducing drag on a submerged, streamlined body by heating the boundary layer and with locating transitional flow with respect to the Reynolds number. One of the key causes of drag on a body is the turbulent flow. If turbulent flow can be changed to laminar flow (the optimum flow over a body), a drag can be drastically reduced, sometimes by a factor of four or five. It is for this reason that this research concerns itself with extending laminar flow and reducing turbulent flow. This was accomplished by heating the boundary layer. By heating the boundary layer, the flow in the transitional boundary layer becomes more stable, thus extending laminar flow. The second aspect of this project deals with distinguishing transitional flow in the boundary layer. This is approached in a unique way, through the use of thermographic liquid crystal. Thermographic liquid crystal has the property of changing colors through the entire visible spectrum, with respect to temperature. Applying this liquid crystal to the test body and following the assumption that turbulent flow will dissipate heat faster than laminar flow, the transition zone should be distinguishable by its color. This zone can then be related to the Reynolds number.

*Send all correspondence

The application of this research can be applied to small underwater vehicles, torpedos, submarines, etc. Its use could be either for energy savings over long periods of time or to allow high speeds for very short periods of time. The energy required to heat the boundary layer could be obtained from the water used to cool nuclear reactors or combustion engines in underwater vehicles.

Problem

Due to this project's unique nature, most of the equipment had to be designed and built. This presented many complex engineering problems which needed to be solved before any experiments could be conducted. It is for this reason that the engineering problems are stated separately from the experimental problems.

Experimental Problems:

1. Can drag be reduced on a submerged streamlined body by use of a heated boundary layer? If so, how is the temperature of the boundary layer and the length Reynolds number related to the drag on the body?
2. Can thermographic liquid crystal mapping be used as a means of detecting various flow patterns on a submerged streamlined body?

Engineering Problems:

1. Can a high speed, open jet, low turbulence water tunnel be developed with the ability to create a critical Reynolds number on a 17.5 cm test body?
2. Can a test body be developed with the capabilities of distributing an even and steady temperature to its walls?
3. Can a measuring apparatus be designed and built with the capacity of measuring minute drag forces on a body underwater, approaching a magnitude of 1.0×10^2 newtons?

Results

Comparison Charts

		FORCE ON BODY (gm cm/sec^2)			% DROP IN FORCE	
REYNOLDS# ($\times 10^5$)	VELOCITY m/sec.	20°C Body ($\times 10^4$)	40°C Body ($\times 10^4$)	60°C Body ($\times 10^4$)	40°–20° (body)	60°–20° (body)
2.03	1.30	0.30	0.24	0.59	20%	33%
2.48	1.59	0.51	0.39	1.21	24%	20%
2.87	1.84	0.81	0.67	1.74	21%	27%
3.2	2.05	1.05	0.86	2.26	22%	27%
3.51	2.25	1.46	1.10	3.18	25%	26%

Conclusions

Heating the boundary layer of a submerged, streamlined body can be a very effective method of reducing drag. In this research, tests were run at relatively low length Reynolds numbers (specifically between two hundred and four hundred thousand). These tests were run with the temperature differential of the body wall to the tunnel water, 40°C and 60°C. The results showed that a higher reduction in drag was found at a 60°C differential than at a 40°C differential. The 60°C body yielded an average over the full

Reynolds number range of 26.6%, while the 40°C body an average of 22.4%. The reduction in drag appeared to go down as the Reynolds number went up for the 60°C body, while the opposite seemed to be true for the 40°C body.

Using thermographic liquid crystal as a means of mapping the temperature zones on the heated body proved to be very successful. The liquid crystal clearly illustrated where transitional flow occurred over the body as well as the length of the turbulent flow regions. From pictures of the body coated with liquid crystal, it was possible to gain quantitative results. These results were related to the length Reynolds number. The relationships showed that as the length Reynolds number increased, the length of laminar flow to the transitional region decreased, and the length of turbulent flow increased. Both of these relationships were relatively linear.

Discussion

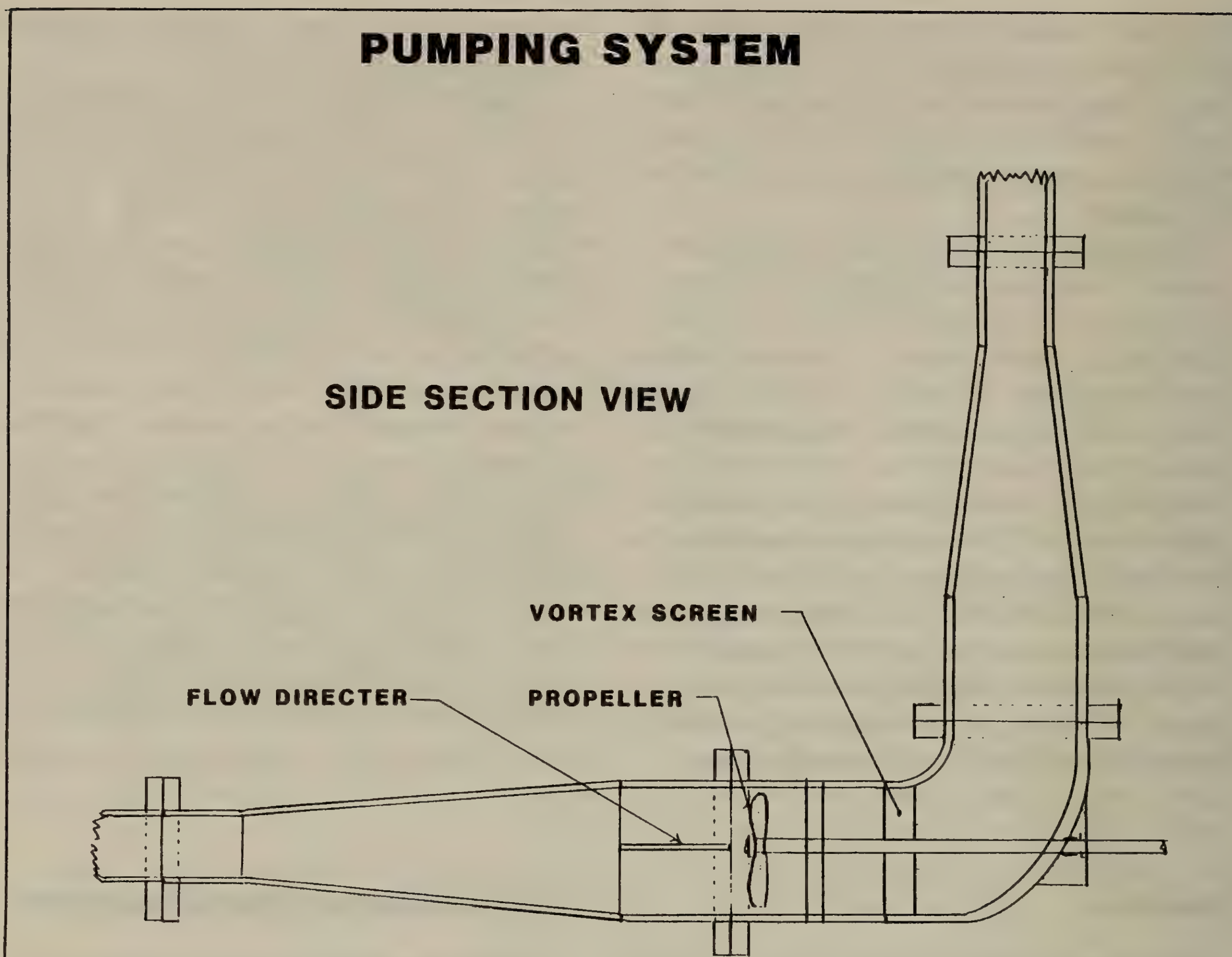
From the results and conclusions of this research, it is evident that heating the boundary layer of a submerged streamlined body can significantly reduce its drag. There are several reasons why this is believed to happen.

The heated boundary layer method of drag reduction works on extending laminar flow. It is for this reason that a transitional body (partly laminar, partly turbulent), is required for the theory to work. If the flow over the body were to be completely laminar, there would be no laminar flow to extend. If the flow over the body were to be completely turbulent, laminar flow could not be started again. It is believed that by heating the boundary layer, the viscosity of the water in the boundary layer is decreased. This decrease in viscosity allows for a more stable velocity profile, and thus allows for laminar flow to be extended. Because laminar flow creates far less drag on a body than does turbulent flow, the drag is decreased.

A last note should be made pertaining to the critical length Reynolds numbers. The critical length Reynolds number for a submerged streamlined body usually lies between six hundred thousand and six million (critical Reynolds number meaning where there is transitional flow over a body). All the experiments run in this research were at length Reynolds numbers between two and four hundred thousand (higher numbers could not be obtained due to the difficulty in reaching the necessary velocities). At these low length Reynolds numbers transitional flow over the body would not be expected. However, this was proven to be wrong by the thermographic liquid crystal temperature mapping. It is believed that transitional flow occurred at the relatively low length Reynolds numbers due to the intensity of the turbulence in the water tunnel.

Brief Description of Testing Equipment

A streamlined body was constructed out of $\frac{3}{4}''$ aluminum rod, with a wall thickness of $\frac{1}{8}''$. The length of the body was 7″. The body was heated by circulating externally heated water through it. The temperature of the body was measured by a thermister. The body was tested in a home built open-jet water tunnel, with a velocity range of 2–8.8 feet per second, controlled via an adjustable pully. The water was propelled by a home built water pump, with a maximum capacity of 11,600 gallons per hour. The pump consisted of a slightly modified 8 $\frac{3}{8}''$ outboard motor propeller mounted in an 8 $\frac{5}{8}''$ pipe. The water was routed to an octagonal observation box where the water was allowed to flow in an open jet. It was in this section that the body was mounted. The force on the body was measured in the suspension apparatus by a strain gauge mounted on a cantilever system that was directly connected to the body.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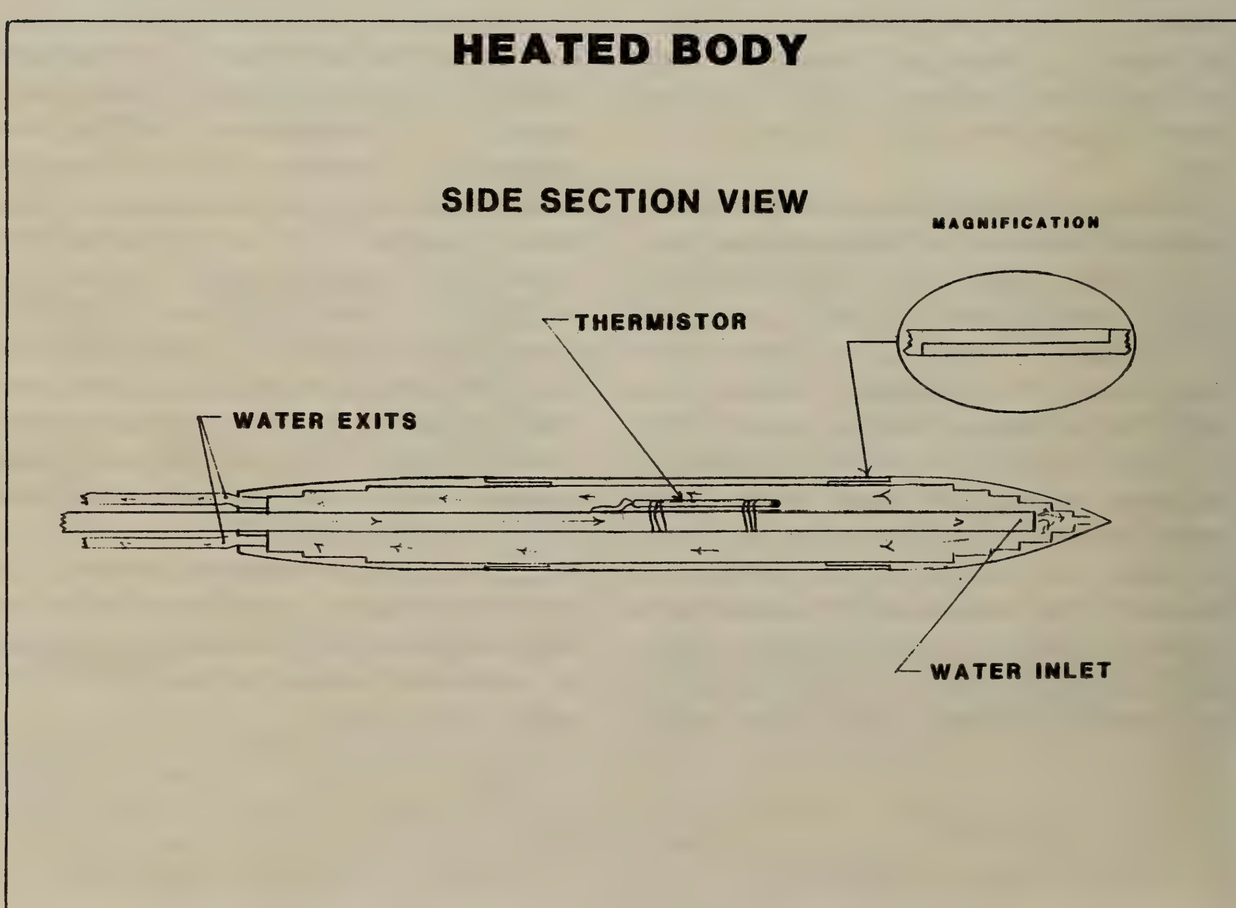
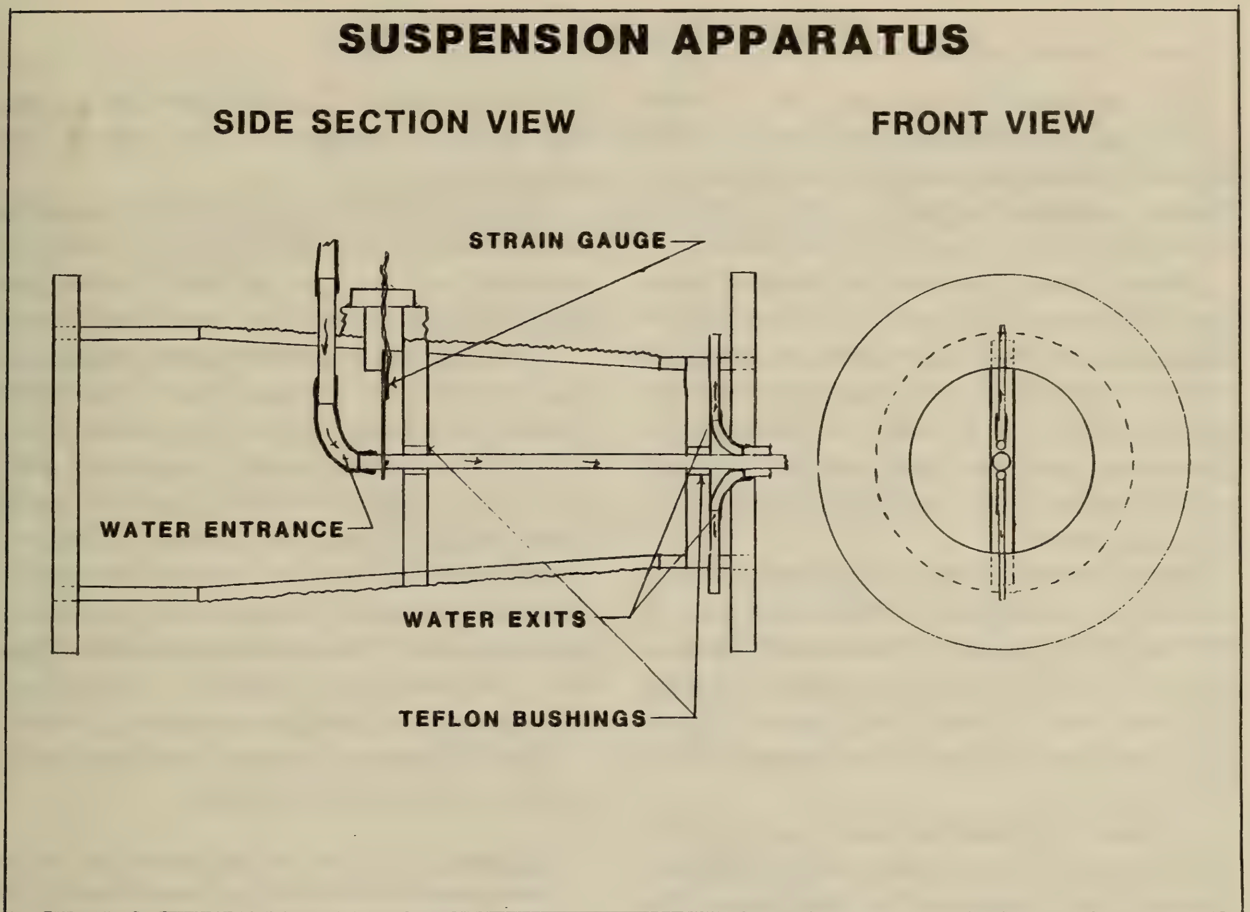
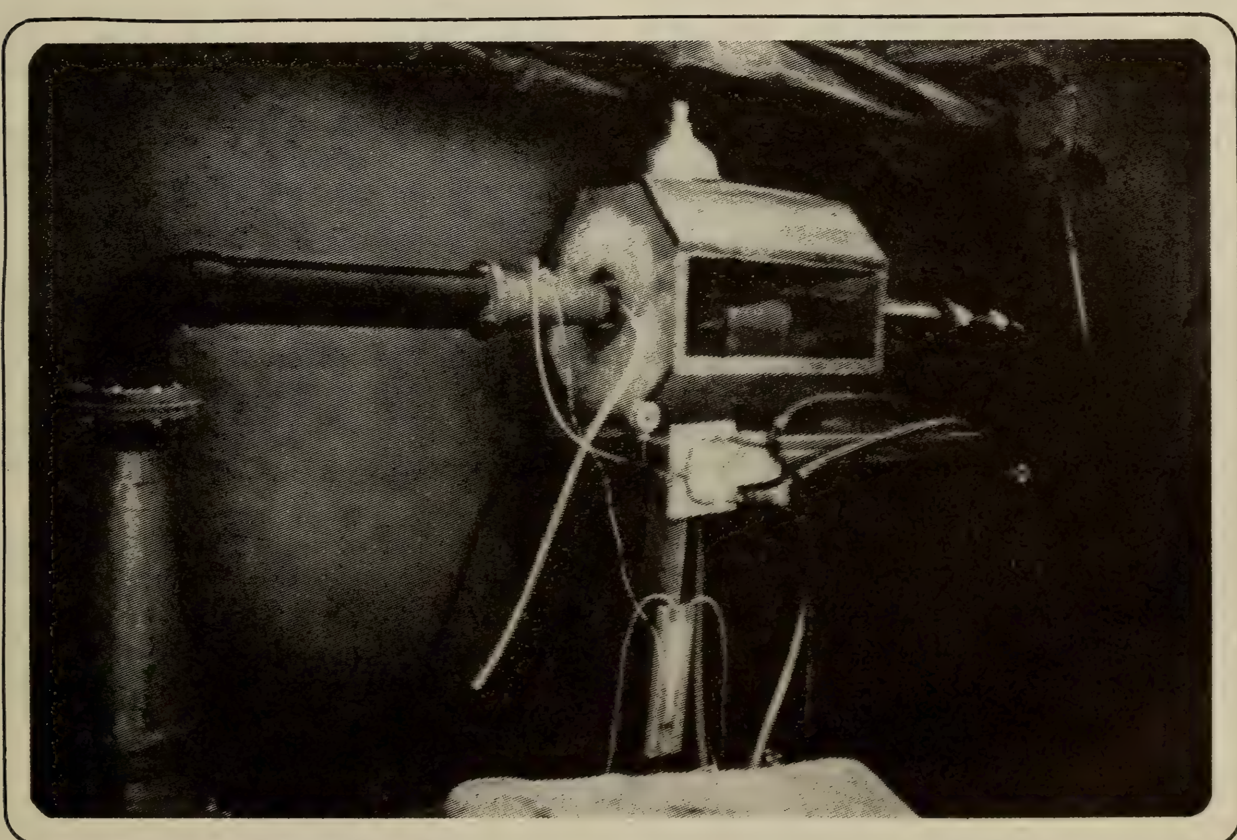
SIDE SECTION VIEW
VORTEX SCREEN
FLOW DIRECTER
PROPELLER


HEATED BODY
SIDE SECTION VIEW
MAGNIFICATION
THERMISTOR
WATER EXITS
WATER INLET


SUSPENSION APPARATUS
SIDE SECTION VIEW
FRONT VIEW
STRAIN GAUGE
WATER ENTRANCE
WATER EXITS
TEFLON BUSHINGS



Journal of the Washington Academy of Sciences,
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The following illustrate the form to be used in the list of references.

1. **Coggeshall, R. E.** 1967. A light and electron microscope study of the central nervous system of the leech. *Hirudo medicinalis.* J. Neurophysiol., **27:** 229–289.
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Send completed manuscripts and supporting material to: The Editors, Journal of the Washington Academy of Sciences, Department of Biology, Georgetown University, 37th and O Streets, N.W., Washington, D.C. 20057.

ERRATA

On page 75 of volume 74, no. 3, Journal of the Washington Academy of Sciences, the following three corrections of typographical errors should be noted:

$$A\{\partial_t M - \partial_x(\beta L - \alpha M) + \partial_z(\gamma M - \beta N) + \beta B\} = -\partial_x Z + \partial_z X$$

$$F_{23} = V_z M - V_y N$$

$$\nabla \times [(V_z M - V_y N)i + (V_x N - V_z L)j + (V_y L - V_x M)k]$$

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This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

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Journal of the Washington Academy of Sciences,
Volume 75, Number 1, Page i, March 1985

Commentary

Journal of the Washington Academy of Sciences Call For Papers

With the issuance of Volume 75 of the Journal, the editors invite the submittal of articles and papers from the scientific community for publication. We welcome contributions from the many disciplines represented by the societies affiliated with the Academy. Papers from members should fall into one or more of the following areas:

- An historical perspective
- Current status or general review of a subject
- Recent research results
- New directions for the future
- An editorial or commentary
- News, announcements, letters

In addition, the editors would be pleased to consider thematic issues, seminar or symposium proceedings and guest editorships that reflect the interests and commitments of the Academy's members.

All papers may be subject to regular review procedures at the discretion of the editors. A copy of the "instructions to Contributors" is included in each issue. If there are any questions, please contact the editors.

In this issue, the Journal presents a reflective examination of the future of undergraduate education with papers prepared by Deans from Georgetown University, the George Washington University, Gallaudet College, and the American University. We expect that their contributions will stimulate both the academic and business communities to air their views on this and related topics through the medium of this Journal.

Future issues will deal with energy conservation, management, and alternatives, the archaeology of the Chesapeake Bay, the museum as an educational institution, and a variety of individual contributions.

The Editors:

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Journal of the Washington Academy of Sciences,
Volume 75, Number 1, Pages 1–6, March 1985

Circumstances of Undergraduate Education: Reflections and Questions

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Georgetown University, Washington, D.C. 20057

During the past year educators, parents and representatives of government have perhaps as never before been scrutinizing the nature and quality of undergraduate education. Concern for the humanities in the liberal arts tradition has been especially a matter for thought and reflection. Evidence of such scrutiny and concern is abundant. The Department of Education recently issued a report sponsored by the National Institute of Education. Entitled *Involvement in Learning: Realizing the Potential of American Higher Education*[1] it briefly examines the achievements of higher education and the ways and means of improving its quality.

Mr. William Bennett, Chairman of the National Endowment for the Humanities, in a recent paper[2] writes that "most of our college graduates remain shortchanged in the humanities"[3] and puts the responsibility for such a failure in education "principally with those of us whose business it is to educate these students."[4] He continues:

> "We have blamed others, but the responsibility is ours. Not by our words but by our actions, by our indifference, and by our intellectual diffidence we have brought about this condition. It is we the educators—not scientists, business people, or the general public—who too often have given up the great task of transmitting a culture to its rightful heirs."

In February 1985 the Association of American Colleges meets in Washington, D.C. to consider "Quality and Coherence in Undergraduate Education." And in March in Chicago the American Association of Higher Education will focus its thoughts on the topic "The Undergraduate Experience: From Taking Courses to Taking Charge."

It is interesting to note, I think, that the cry for reform and renewal of the liberal arts curriculum seems to come today more loudly, more consistently, from faculty, parents and those outside the campus than from the stu-

[1]U.S. Department of Education, National Institute of Education, Final Report of the study group on the Conditions of Excellence in American Higher Education, *Involvement in Learning: Realizing the Potential of American Higher Education,* 1984.

[2]William Bennett, "To Reclaim a Legacy. A Report on the Humanities in Higher Education", *The Chronicle of Higher Education,* XXIX (November 28,1984) 11, p. 16.

[3]*Ibid.*

[4]*Ibid.*

dents themselves. This generation of youth seems different from the one of the late sixties and early seventies. In those days of protest and cry of conscience the students called for "relevance" in courses and programs and many a college faculty responded by experimental courses and changes and/or elimination of core requirements. By "relevance" the students then meant not so much "practical" as courses well taught which had meaning for their individual and personal development. For them, the yellowed musty lecture notes of the faculty and the grade consciousness of the students symbolized the opposite of the active learning they desired. They wanted a clear initiation into involvement in the world they sought to reform. Today's generation's request is for usefulness and practicality for there is great pressure to seek as immediately as possible the next step which is to be professional and career success. Yuppies are for many students the secular saints to be imitated now and joined later.

Why does the topic of undergraduate education and a concern for the liberal arts tradition demand the attention of so many faculty members, parents, college administrators, and government representatives today?

Because for hundreds of years in the western world the education of young people in their teens and early twenties has been based in what has come to be known as the liberal arts—literature and history, language and the sciences, philosophy and theology and the fine arts like drawing and music. Universities in each period of history have struggled to use such courses and to arrange them along with, more recently, the social sciences, into curricula or programs which sought to meet the needs of the times in which their students lived. No one formulation necessarily fits all times but the skills to be learned in the liberal arts were those of clear writing and broad reading, critical thinking and the making of right judgments. Sensitivity to beauty, compassion in the service of others and patriotism were virtues to be prized as they were developed through disciplined experience and reflection. In its ideal, the education was for living a human life, not just for earning a living.

On today's college campuses, many feel that the ideal of such a liberal arts education needs rediscovery. Such education is not yet dead but it is in danger of dying. It is seen, when operative and effective, to be both relevant and practical. Though not directly and exclusively related to careers it affords a student the opportunity for the free pursuit of professional and business success. It has the potential for teaching the individual to be a free citizen in a free society.

To make an attempt at the rediscovery and renewal of this kind of undergraduate education requires that colleges today do as colleges have always done in the past when renewing programs of study. They must pay serious attention to the circumstances of undergraduate education on today's campuses, to those conditions which determine whether or not undergraduate educational experiences will be fruitful and rewarding not only for the individual students involved but also for the society of which they are members and for the world of which they are citizens. What circumstances are peculiarly relevant in the renewal process? What circumstances affect students today that must be considered in the educational preparation of those students for adulthood tomorrow? Let us reflect on three circumstances: the peculiar pressures to be practical which today's students face while in college, the state of teaching, bad and good and its natural extension, student advising; and the curriculum—How narrow is it? How does it offer the experience of creating? How does it present the relation of science and technology to human society? and How does it introduce students to the responsible service of others?

The pressure to be "practical" is usually understood to mean that one's college education should be of such a kind as to be of immediate use in the world after college—the world of profession and business. The college student is not to be encouraged to savor his education but rather to see in it a job-securing instrument. It is the immediate, not the remote, key to success and fortune. That present day students perceive this as a goal of education is borne out by a recent survey of college freshmen, reported in the

Chronicle of Higher Education.[5] One startling statistic indicates that 67.8 percent of the students surveyed said a very important reason for attending college was "to make more money," and 75.6 percent thought it essential or very important "to be very well-off financially," while a distressingly low percent (44.6) found it important "to develop a philosophy of life."

There is added pressure on students in liberal arts colleges which are joined to schools of business or other pre-professional schools. They sometimes feel threatened by the apparently self-confident business or pre-medical student who seems to know what she or he is doing and where the doing will lead.

The pressure comes often from parents, who understandably wishing the best for their sons and daughters pay heavy tuition costs and hope to see such a heavy investment return dividends in the success of those sons and daughters upon graduation. The pressure is present to the students themselves who must face the peer who asks, "What's your major?" and upon replying hesitantly "English" or "History" must face the peer's final condemnation, "What in the world will you do with that?" The student could then reply "I don't know, but I like it." or "At least I'll be able to read and write." More than likely, however, the condemning question will end the conversation. Failure to choose a socially acceptable major today causes many a student heart burn! Yet the major ideally should not be seen as a distinct entity, separate from the entire educational endeavor. It is rather that academic discipline which gives some focus to the students' education. It is complemented or deepened by their elective choices, and is ideally that area which the student likes sufficiently to spend serious time studying. The result of such an approach to a major is a happier student, doing better academically, growing in a sense of self-confidence and ultimately having better choices upon graduation.

Pressure to be practical, whether it be direct or subtle, tends to rob the student of a kind of freedom to choose and to experiment imaginatively with his or her own education. Too often choices of majors and programs are viewed as *life* choices, when such choices are of significantly less importance.

Obviously some academic disciplines have a *direct* relationship to post graduation careers, e.g., a major in accounting, or nursing. The criteria for choosing such a major, however, should remain the same, if the undergraduate truly wishes to reap the full benefit of his college years.

The primary counter-balance to these kinds of pressure to be practical, I think, lies in good teaching and good advising of the individual student (and parents)—teaching and advising go hand in hand. They *are* the education of the student. They offer the invitation to learn. They pave the way for choice. They stimulate imagination and curiosity so that the work of learning, as lonely as it may sometimes be, is never without encouragement.

Poor teaching, on the other hand, contributes to the pressure surrounding a student's education. It manifests itself in so many ways—ill prepared lectures repeated year after year, courses filled with busy work, courses in which content must be covered regardless of time or active "audience" participation, lectures given with materials far beyond or far below the intellectual capacity of the students, courses which are too large to allow for any exchange between professor and student—which reduce education to lectures, wisdom to mere information.

Into the undergraduate college have come the worst aspects of the graduate school mentality—an over-professionalization of the faculty and a very narrow disciplinary agenda shaped by graduate schools. The teacher teaches only what he has carefully studied in graduate classes and is frequently not encouraged to use his own imagination and intellectual ability. The result more often than not is poorly presented lectures of a narrow and confined nature. This makes for a truly deadening teaching effort especially when the course is required as part of an attempted

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[5]Thomas J. Meyer, "Freshmen are Materialistic but not Conservative, Study Finds," *The Chronicle of Higher Education* XXIX (January 16, 1985) 18, p. 1.

liberal arts experience in learning. If a course is ''required,'' if it is to have any effect other than simply the amassing of credits necessary for graduation, it must be well-taught, literally seducing the closed-minded to be open to what it offers and encouraging the already converted to see and understand how and why this subject matter, these readings will contribute to his intellectual and personal development.

Poor teaching can also result from an undue emphasis on published evidence of a scholarly mind. No one will deny the real need for scholarly minds in undergraduate teaching and no one will deny that published articles in appropriate journals and published books can be tangible evidence of scholarly alertness but publication for publication's sake may simply draw the teachers from the prime time they should dedicate to the teaching of young collegians. Some of the most adroit and accomplished teachers I have known have been scholarly and wise and yet their published works were modest in number. As the amount of published material continues to grow, we should look to its quality just as we should look to the quality of teaching whether the number of students taught in a class be 10 or 110.

Research is vital to the life of the university and to the life of the college. On the undergraduate level, good teaching drawing on the intellectual spirit, constantly renewed in research is, every bit as vital to college life—for in education there is both a drawing from the world around us and a handing on to those who are young what has been learned. The good teacher has sympathy and understanding for the work of his or her colleagues in other departments. The students see the point of a liberal arts education because in his or her teaching it is clear that breadth and integration of knowledge is important. Set fire upon the earth. Let young men and women see visions and old ones dream dreams.

Advising a student is an extension of teaching. On one level, it may merely be the directing of a student to the courses necessary for his degree. On a deeper level, it requires the advisor, whether it be a teacher or a counsellor in an advising center, to know the student, his interests, his background, and his skills. Ideally there will exist a mutual respect between advisor and advisee, a kind of friendship, which allows free conversation in which questions are nor feared now answers avoided, in which both admonishment and encouragement have their part to play.

Advising is especially important in aiding students in the process of making informed choices. It is equally important because it invites the students and advisor to know one another. The students can experience the healthy dependence needed in the learning movement towards adulthood. For a young college man or woman to come to know a teacher in this way is for that student to begin truly the college learning experience. It can mark the move from dependence on family to dependence on self, a dependence which does not deny the need for consultation.

Students learn from books and lectures, but as young men and women they are very susceptible to learning by way of imitating those whom they admire and respect. The teacher as advisor can easily be the one to be so imitated. The imitation is obviously not to be one of mannerisms and style of dress but rather one which imitates ways of solving problems and thinking and searching for solutions. The good advisor-teacher is often the one whose example invites the student to consider a particular field of study which may be the advisor's own or who introduces the student to new horizons of career and professional goals. The importance of a *friendly* advising relationship cannot be underestimated in making the undergraduate experience fruitful and rewarding.

Related to the quality of teaching-advising which when it is poor lets the humanities and all subjects die, is the state of the curriculum. How is it put together? How is it taught? Are its required courses, if any, inflexibly dull?—so many mountains to climb and so many holes to sidestep? Is the cirriculum so rigid that it binds the mind just as an overly starched collar binds and chafes the neck? How often is it reviewed and evaluated or has it been established in a garden of Eden which no longer exists?

Every curriculum must be periodically reviewed, evaluated and then renewed. This proposition is as true for a curriculum which

has no particular requirements as it is for one which is rigid with the structure of required courses. The process of renewal is not simply "up-dating" by brashly eliminating the past. Nor is it simply a matter of gluing together new courses or programs. It requires questions and reflections on the nature of the times and the needs of this generation. It is a politically and philosophically difficult undertaking-politically difficult because faculty and departments tend to fear in change the invasion of their own academic turf. Will that departmental turf be cut back while another's is enlarged? In so many institutions of higher learning the departmental kingdoms know little of the vision of a college at the service of students who are to be educated for their day's world. As a result, instead of offering a diversity of courses in different disciplines which point towards an integrity and unity of knowledge and learning, the kingdoms remain balkanized—more often than not each turned in upon itself. No wonder students often graduate indifferent to further academic learning and the world passes by, without interest, the ivied walls of academe.

The process of curriculum renewal is also philosophically difficult because if the process is to be successful wise heads must seek patiently to clarify the goals of the institution and to understand its traditions. They must then patiently and broadly consult and build towards an acceptable renewal and reformation.

An interesting account of Harvard College's ten year journey to the center of the curriculum may be found in *Getting at the Core: Curricular Reform at Harvard.* It was written by a participant in Harvard's journey to reform, Phyllis Keller, an assistant dean during that period. In the preface Dr. Keller writes:

> "Curriculum change is the most visible way in which that institution adapts to changing conditions in our society. College faculties invest so much of their time and energy in debate over curricular structure because it provides a useful framework for discussing issues of a more complex, fundamental and elusive sort. Here is a familiar battleground—a practical vocabulary—for the task of competing educational values and ideas, and for striking a workable compromise among the claims of the academy's internal constituencies."[6]

The importance of the periodic review and reform of the undergraduate curriculum cannot be underestimated. Every serious review contributes to the vitality of the college's intellectual life. The review itself can foster the sense of shared academic community in which there should be the challenge and discussion of alternative ways of achieving the college's goals and objectives in accordance with its traditions.

As the review process begins, faculty and administration must pose questions about what is needed today to make the curriculum a vital learning guide for the students in preparing themselves for fruitful lives upon graduation.

The first such question that might be asked is how narrow is the curriculum? i.e., does it focus only on one's own nation and culture or does it invite and direct by suggestion and requirement that the student look beyond? In a world which has grown as small as ours, there is no reason for a curriculum to focus only on the tiniest part of the world—one's own. The knowledge of a language and a culture other than one's own would seem a necessary virtue in any academic program of today. Understanding and tolerance of, and respect for, the thinking and the ways of others are necessary elements in bringing peace to a world harried by violence and the threat of war.

An invitation to learn about other cultures and so to learn *from* them are means to expand one's own knowledge. Perhaps the students of today will be readied thus to see the oneness of the human race and to understand themselves as members with responsibility for its well-being.

The second question to be raised has to do with the matter of science and technology, and their role in the world. How does the curriculum encourage the students to raise

[6]Phyllis Keller, *Getting at the Core. Curricular Reform at Harvard* (Cambridge, Mass.: Harvard University Press, 1982) pp. viii–ix.

questions about the nature and quality of that relationship?

Such a question presupposes in partial answer that a student be exposed to a serious and intelligent knowledge of science, its history, its methods and its potential. Such knowledge and understanding comes ideally, I believe, in a classroom-laboratory situation through regular contact with a teaching scientist who is active in research. What science has done to our world and our way of thinking and how it has done this, influences deeply how we think and act. Sometimes the influence is direct, sometimes subtle and indirect.

The other partial answer to the question demands that students be encouraged to think in terms of ethical values. What are the effects of science and technology on human life? Because something can be done, is it always good and right that it be done? These are philosophical and theological questions that must be considered in science as in policy matters with the help and fact-finding of the social scientist.

This kind of wonderful wrestling with the achievement of science and technology and their continuing potential to better human society should have an introductory place in the undergraduate curriculum. The result may be more thoughtful citizens after graduation, even wise ones—future leaders of the nations.

The third question asked in any curriculum review is not unrelated to the second. It is this—How does it offer the student the experience of being a "creator," i.e., how does it offer the student the opportunity of wrestling with the material world to test and know its limitations and yet to transcend those limitations by the beauty and discovery he or she effects in the very act of wrestling. Here are involved wit, intelligence, and imagination. The scientist does this and has taught the world to do so. Alfred North Whitehead wrote: "This new tinge to modern minds is a vehement and passionate interest in the relation of general principles to irreducible and stubborn facts."[7]

The sculptor forces his vision upon the stone, knows the stone's limiting qualities, and yet his vision transforms, transcends them. And so the musician with sound and the dancer with movement, the actor with gesture and speech and the writer with the written word.

Such experiences as these—not all, but the opportunity for some—must be offered to today's undergraduate. They foster dreams and give promise of the freedom of the human spirit. They teach the limiting quality of the world in which the student lives but at the same moment suggest the possibility of its mastery. A new respect for the human person can and should be one result, a sensitivity to beauty another. All these are experiences essentially affecting the quality of free human living.

The fourth question to be asked in a curriculum review today has to do with the responsibility that each of us has in service to one another. How does the curriculum introduce the undergraduate to this notion of service? Community service in the inner-city, the tutoring of children, the care of the elderly, the feeding of the hungry, the clothing and sheltering of the homeless—these are opportunities for student activity which lead to a clear awareness of the interdependence of human beings.

Exercises such as these give the young undergraduate an opportunity to experience that he or she is needed by those in need themselves. From this experience can grow sensitivity to others and a growth in his or her own maturity. It instills a freedom to give of what one has to give. It sets a habit of service so especially necessary in this republic and this world.

Ask these four questions in any curriculum review. Ask about its narrowness, the place it gives to science, the presence in it of the creative experience, and its efforts to promote service of others. Try to answer them effectively. Then the curriculum will begin to breath with new life.

Undergraduate education in the United States has much of which to be proud. Its achievements are outstanding. But the world does not stand still. Neither must the education offered to men and women of a free society. The study of the circumstances of undergraduate education through reflection and questions is key to movement and improvement.

[7]Alfred North Whitehead, *Science and the Modern World* (New York: The Free Press, 1967) p. 3.

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Gazing into the Crystal Ball: The Undergraduate Experience in the Twenty-first Century

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"At this University, several factors have operated to de-emphasize the importance of general education . . . . [the purpose of which] is to give students the intellectual tools they need to deal with personal, social, and political issues throughout their lives.

Decentralization of responsibility for the undergraduate curriculum . . . . is probably the most important cause of the de-emphasis of general education . . . This trend must be reversed."

Since last March, when the authors of this statement—senior faculty and administrators known collectively as The Commission on the Year 2000—released their report, I have given a lot of thought to the undergraduate experience at The George Washington University.

Much as some of my faculty would like to evade the issues, there can be no question that they and I, together, are primarily responsible for the quality of undergraduate education at GWU. Undergraduate degrees are conferred by four professional schools (Engineering, Education, Government and Business, and International Affairs) but all candidates for a bachelor's degree take a significant number of courses in the College of Arts and Sciences. Thus, as we move toward the next century, our responsibilities as liberal arts educators seem to be growing rather than diminishing. My contemporaries and I recognize the implications of those responsibilities for our professional identities and for our institution. But we do not find it very easy to face up to them.

At my University undergraduate applications have reached an all-time high. The College of Arts and Sciences is the major beneficiary of the bumper crop of applications, with an increase of about 20% over 1983. As in the past, some of those entering students will choose to transfer to other universities or to one of several professional schools within GWU. But letters of application and interviews suggest that a majority of the entering freshmen have chosen Columbian College of Arts and Sciences because they want a liberal arts education.

My faculty and I are thrilled that GWU is doing so well, despite the diminishing number of high school graduates nationally and the overall demographic decline in the Northeast. We are proud that most entering freshmen are choosing Columbian College, the oldest school at our University, and one with many distinguished alumni. Yet, we are ambivalent toward our collective success and uncertain as to its implications for the future. Many of us began teaching in the 1970s, lean years for arts and sciences programs. Now

we are discovering the hidden advantages of adversity. They have been habit-forming.

The lean years, of course, took their toll on us, professionally and, in some cases, personally. Career advancement was slower and more difficult for us then for those trained in the Sputnik era. Some of us accepted teaching and administrative jobs that to our graduate school mentors were tantamount to a fall from grace. And we watched less able (or perhaps less persistent) colleagues be worn down by once-a-year job changes or by negative tenure decisions. However, if we were competent and lucky enough to earn tenure and to advance to senior academic ranks, we found that we could relax.

At most colleges and universities the decline in undergraduate liberal arts enrollments was severe enough to inhibit the growth of the more traditional departments and to depress average salaries. But it was not severe enough to threaten the jobs of tenured faculty or to mandate drastic changes in the curriculum. On the contrary, many colleges of arts and sciences settled into a mode, halfway between despondency and complacence, that was conducive neither to constructive self-criticism nor to a convincing defense of liberal arts education. As faculty members we were occasionally unhappy with the vocational ambitions of our undergraduate students and with their mediocre verbal and quantitative skills. But most of us were not called upon to help reverse the trend. We were simply called upon to endure it. If the demands of undergraduate teaching were relatively onerous, we looked for ways to stop enduring: we moved to other institutions, if we could, or we turned our energies to graduate education, research, administration or off-campus pursuits.

Educators (including our own presidents and deans), journalists, and politicians blessed our retreat from responsibility for undergraduate liberal arts education. According to the folk wisdom of the 1970s and early 1980s, the trend toward undergraduate professional education was regrettable, perhaps, but inevitable and irreversible. Liberal arts programs, which bore the imprint of their elitist origins, no longer met the needs of a society shaped by advanced technology and corporate organization. Nor, we were told, could they meet the expectations of thousands of first-generation college students for whom a baccalaureate degree was a ticket to an entry-level job.

It was easy enough to believe the common wisdom: we could remain fiercely loyal to the *intellectual* value of liberal arts education while at the same time refusing to take responsibility, vis-à-vis our students and vis-à-vis society, for its declining popularity. The most dogmatic among us argued that the value of a liberal arts education lay precisely in its lack of any practical or "market" application. Most of us did not go so far. In fact, we tinkered with majors and programs that held some promise of post-baccalaureate employment. But whatever our position, we put some distance between ourselves and undergraduate education.

At every turn, especially at commencement exercises, we sang the praises of liberal arts education. But there was only a tenuous connection between our intellectual convictions (however sincerely held) and our investment of professional time and energy. There was no point, after all, in changing the content and method of our teaching or in making a heavy commitment to undergraduate advising if we knew that our students would migrate inevitably to business or technical degree programs. This contradiction in our professional lives was habit-forming. It will be difficult to break away from it.

The apparent resurgence of liberal arts programs is welcome, of course, and in it we find a validation of cherished beliefs. But it comes at a time when most colleges and universities are not in a position to hire large numbers of new faculty. In most cases, we will be asked to do more for undergraduate students than we have been accustomed to do. We can expect that some of our colleagues will stop complaining about "vocationalism" and start complaining about large classes and advising loads.

The pundits who helped us in the 1970s make peace with declining enrollments in arts and sciences are now turning against us. The media, in particular, have commented favorably on the Asscociation of American Col-

leges' report on the baccalaureate and on Education Secretary Bennett's injunction to us "to reclaim [our] legacy," in the form of great books by (mostly) dead white males.

These forms of public criticism make us uncomfortable not so much because they are intemperate and unjust (academics have endued worse things, such as the Scopes trials and the McCarthy hearings), but rather because they expose the contradiction within ourselves and in our institutions between theory and practice, between beliefs and policies.

The politics of the various reports on undergraduate education matter less than the expectations of students who again are choosing to major in arts and sciences programs. We do know some of the factors that influence college choices. First, the classes of 1989–1994 will face less severe competition for entry-level jobs than did the classes of 1979–1984. Second, the recent shift of a few large employers, such as IBM, from hiring people with technical degrees to hiring mathematics and English majors has had an immediate (and probably excessive) impact on high school counselors.

Does this seemingly idiosyncratic phenomenon of the 1980s portend major trends in American higher education for the twenty-first century? It might, if we accept the challenge that is presented to us by the current public debate on undergraduate education and also by the increasing emphasis on lifelong learning in the workplace.

The challenge is awesome. We are being asked to put undergraduate education at the center of our professional lives and of our institutional reward systems. As if that were not difficult enough, we are also being asked to rethink the meaning and purpose of the baccalaureate degree. Not to change this or that requirement, not to add new subject matter, not to integrate experiential with classroom learning, but *to rethink the whole experience*.

IBM's decision to hire mathematics rather than computer science majors has nothing to do with a philosophical bias in favor of liberal arts programs and probably very little to do with the fact that its top executives tend to be graduates of prestigious liberal arts colleges. The decision has a lot to do with IBM's perception of its need for human capital and of the relationship between capital investment and long-term profits. In an industry that is highly competitive and subject to extremely rapid change, IBM needs people who understand the mathematical bases of computer technology more than it needs people who can work with one or another type of software or equipment. Recruiters take for granted the need for continuing professional education and are prepared to provide opportunities for it, on and off the job. Ideally, they want to invest in people who are interested in learning, not just earning, and who are not afraid to master new concepts or fields of study. They also take it for granted that job-related skills acquired in college become obsolete within five to seven years of graduation.

Liberal arts and sciences programs can help future workers and citizens to become interested in learning, to cope with change, to think logically, to speak and write effectively. But these desirable outcomes do not occur automatically and they certainly do not occur by osmosis, through the accumulation of a prescribed number of courses distributed in a prescribed way.

At my own institution, and many others, the arts and sciences undergraduate curriculum reflects the past more than it portends the future. The recent past, the bitter sweet years of declining liberal arts enrollments, is reflected in distribution requirements carefully balanced to assure that each department gets at least a minimum number of available bodies. In other ways our curriculum recapitulates the long history of liberal arts education, at least in its American forms.

The requirement that students choose a certain number of courses from the humanities and from the studio or performing arts is evidence of an era when undergraduate liberal education was one of the hallmarks of elite status. The main purpose of a baccalaureate degree was to give those who earned it a common cultural experience that set them apart from their contemporaries. That sometimes the degree was also useful as preparation for a profession was not accidental, perhaps, but

certainly was of secondary importance. Thus, for instance, in the second half of the nineteenth century elite women's colleges were founded and thrived not because they promised their middle and upper-class women students useful training but because they offered those students the same cultural experience already available to elite men. In the era of mass higher education, we retain some aspects of that experience, but we seldom bother to explain to our students why we do so. Is it any wonder that, especially from students who grew up in homes without books and artefacts, we often hear complaints about "irrelevant" requirements?

Ambivalent as we sometimes are about the legacy of elite education, we give students considerable freedom to specialize and to choose professional or preprofessional majors. At GWU, scores of students choose economics, political science, zoology, and psychology in the belief that specialization in one of these subjects will prepare them well for lucrative professions. We complain about "rampant vocationalism" and tell our students that art and music, philosophy and literature are good for their souls. But we lack a coherent rationale for rejecting a utilitarian view of liberal arts education. Deep down, we are aware that for many of our generation the baccalaureate degree has been a ticket to material well-being and middle-class status. We are reluctant to call our students to task for values and beliefs that the experiences of our contemporaries on the whole tend to validate.

To add to the confusion, a curriculum that straddles uneasily between elite culture and utilitarian impulses also reveals our efforts to respond to the exigencies of the very recent past—the advent of mass higher education, the decline of SAT scores, the controversial influence of television on students' literacy. Thus, we accept (grudgingly and apologetically) the teaching of basic grammar in freshman English classes; we give college credit for algebra courses; and we offer very abbreviated summer sessions.

On my own campus, few faculty and administrators are comfortable with the legacy of the very recent past. They hope it will fade away as secondary school standards are tightened and as our admission policy becomes more selective academically. This is not surprising because most of us in positions of leadership at GWU were educated well before the days of remedial English and remedial mathematics for freshmen. Indeed, our deep-seated conviction that such courses are not legitimate components of the baccalaureate experience often stands in the way of attempts to develop, evaluate, and fund effective remedial programs. For better or worse, however, a broad consensus does exist on this part of the undergraduate curriculum.

The consensus breaks down when we try to come to terms with the older legacies which our undergraduate curriculum mirrors and, like most mirrors, distorts. Some of us are deeply committed to the notion, however utopian it may seem in the late twentieth century, that the baccalaureate experience should set an intellectual elite of cultured men and women apart from the masses. However, we are not at all certain that a democratic society can nurture an intellectual elite without also nurturing social and power elites. Moreover, when we try to design an elite education that is not ridiculously anachronistic we disagree sharply on its content. Usually we end up arguing that our own discipline or subdiscipline must be the pivotal one in the undergraduate student's difficult progress toward enlightenment. Thus, the curriculum becomes a hotly contested battlefield and the rich educational experience we want sincerely for our students becomes a smorgasbord table.

Until quite recently, those of us who took a utilitarian approach to the baccalaureate degree and developed professional or preprofessional curricula in such areas as ecology, journalism, radio and television, or actuarial science, had it easier than our elitist colleagues. We argued that a job-minded generation of students would give up on liberal arts programs altogether unless we recognized the legitimacy of their interests and concerns and found ways to adapt our programs accordingly.

Our values and goals are not so clear now.

We are reeling from the blows of criticism and condemnation dealt to us by highly publicized national studies of undergraduate education. And we are discovering that once popular job-oriented programs of study no longer attract students and are a bigger drain on our resources than the traditional disciplines.

Too few of us, elitists or utilitarians, are looking at the undergraduate curriculum in the broader context of cultural, economic, and social changes in this country and abroad. *What is needed is a vision for the future and not simply a reinterpretation of the past.* It is possible, I am convinced, to be proud of our intellectual legacies and responsive to the short-term preferences of our students without becoming enslaved to either. At a minimum, we must understand clearly what undergraduate education is *not* about in the late 1980s: it is not about preparation for a life of leisured refinement, as it was for nineteenth century gentlemen and ladies of means; it is not a passport to a life of stable employment, residence, and social relations, as it was for the organization men of the 1950s; it is definitely not a substitute for continuing professional education, the only growth sector of the educational enterprise and one increasingly shaped by major corporations, not by universities.

Although we can only see the contours of the next century, some reasonable assumptions should guide our plans for undergraduate education. One assumption is that higher education will continue to be a mass phenomenon. Another is that the ''knowledge explosion'' characteristic of this century will continue and probably accelerate in the next. Thus, it will be ever more difficult to agree on the specific content of a four or five-year course of study. And finally, we can assume that future graduates routinely will experience several changes of employment, residence, and family and social relations during their adult lives.

If we accept these assumptions, we come to the conclusion that the primary purpose of all formal education, and especially of the undergraduate college years, must be *to learn how to learn.* It may be important that students be exposed to all facets of human knowledge and that they study this or that subject in some depth. But surely it is more important that students develop—by whatever combination of subjects—a high level of ability to communicate, to reason, and to understand and cope with the demands of a constantly changing world.

This view of undergraduate education, however, runs counter to the academic trends of the past twenty years at my own and at many other universities. It implies that disciplinary boundaries should be largely irrelevant to the curriculum, and departmental boundaries even more so. It certainly calls for the demise of carefully negotiated distribution requirements and ultimately, perhaps, for the demise of traditional majors. *Above all, this view calls for a revolution in the role of the teaching faculty.* Once role models of intellectual sophistication and genteel behavior, we have become primarily transmitters of discipline-based knowledge and values. We are unprepared, and in many instances, I suspect, unwilling and unable, to refocus our teaching around general intellectual abilities rather than around disciplinary paradigms.

We do, of course, have the option not to move in this direction at all and to muddle through, as we have done more or less successfully since the founding of Columbian College in 1821. Most of us find it comforting, and certainly comfortable, to stay with values and educational strategies that are familiar, that are part of our cultural heritage, and that are reasonably compatible with specialized research, consulting, or other non-teaching professional activities.

To depart from habits and traditions is always difficult. It is more difficult when there are few models for change and when the institutional rewards favor the status quo. It is almost heroically difficult when we are asked to change our outlook, aspirations and working conditions for the sake of younger generations that may or may not perceive the magnitude of our sacrifices and may or may not benefit directly from them. As we ponder on these issues, it might be useful to remind

ourselves that the students we will educate in the next fifteen years will have no choice but to cope with the unfamiliar and to interact with cultures very different from their own. As for our attachment to specialized subjects or courses, it might be useful to admit to ourselves that some are already obsolete (that is, they no longer represent the cutting edge of new research in our disciplines) while others will have become so by the twenty-first century. We should not be ashamed of cherishing them, but neither should we claim that they are indispensable to the education of tomorrow's liberal arts graduates.

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Education in the Liberal Arts

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Being asked to comment about a topic as general as "education today" is similar to being asked to design a new internal combustion engine. One knows or can research the basic operating components, but to come up with a new or innovative approach or concept can be quite difficult. Therefore, I will only express my personal opinion about where education seems to stand now and where I think we should stand. I do not wish to ignore or denigrate any other type of postsecondary institution, but I will focus on the liberal arts and sciences because that is the arena I know best. Since there have been so many articles and national reports pubblished recently, I will not offer another definition or listing of what a liberal arts education is, but I will focus on what I feel are two key aspects: content or skill building and problem solving or the higher cognitive processes.

It seems at times that we as educators have to re-determine what our priorities are. The traditional value of education in the past was that it attempted to graduate students who had learned how to think for themselves, i.e., they learned how to absorb masses of information, analyze that information, process it and arrive at a solution to a problem. I feel that these aspects still are and should continue to represent the value of an education. Instilling in students the ability to think clearly and critically and to be intellecturally sophisticated and well-read individuals should be the ultimate goal of a liberal arts education. A graduate with these abilities will continue to be sought out by a variety of firms and agencies which seek not specialists in a given field, but generalists who have learned how to learn and can easily be taught any necessary, specific new skills.

It is obvious that for students to reach the point where they can learn, process, analyze, and synthesize, they must first gain a solid foundation in skills such as reading, writing and mathematical computation. These are the basis for all other learning which should happen in our colleges. If we have students whose skills are weak, we must first bolster their skills and content levels before a student fully participates in the rest of the curriculum. I have told students that I cannot teach them anything in the true sense of the word, but I

can help them to learn. Once skills are attained, we need to provide increasingly larger masses of information to our students. But the major concern of a liberal arts institution is to help students learn for themselves or to show various methods of dealing with and processing information. Basic information can perhaps be better obtained outside of the classroom. What must happen inside the classroom is that the instructor, the mentor, the tutor, illustrates how conclusions can be drawn from various data and information.

We must perhaps think in different terms when we deal with basic skills as opposed to a real knowledge in a subject. In language acquisition for example, a student must first learn that a particular noun has a definite relationship with a verb. He need not know why this is true but can simply memorize the fact that is is true. This skill building level in language must precede a deeper knowledge of the complexity of the grammatical structure of a language. Baasic skill must come before that graceful manipulation of a language we call good writing.

I can memorize, on my own, methods of identifying various minerals. One role of the teacher is to quicken the process by which I memorize those methods or give me practical, hands-on experience in learning to identify those minerals. The teacher can speed up the process of rote learning but more importantly can illustrate for the student methods of dealing with what is being learned. It has been said that a college education is comparable to ten years of living in the active world. It seems to me that this statement is basically true. A college education enhances and compresses the acquisition of knowledge. However, a person can live for ten years and learn very little. A student can spend four years in a liberal arts college and learn very little. If one goal of education is to give students the ability to problem solve and to make intelligent and critical decisions, then all curricula and all teaching methodologies must be geared toward achieving that goal. I suggest that we must stop teaching our specific fields in isolation and must show the interrelationships among academic disciplines. The current trend toward Writing Across the Curriculum is a good example of teachers from a variety of fields working toward a common goal. We also need to explore more fully the power of interdisciplinary courses.

We should not forget that skills are taught on all levels, on the remedial or developmental level, on the freshman/sophomore level, and into the major level. This is true at most levels with any discipline. In art, I first must teach students as well as I can how to use a pen or brush. I can most likely train students who have sufficient physical capability, teaching them to do line drawings or perhaps teaching them to do oil painting. But to become good artists, they cannot simply be copyists; they must put something of themselves into their art and make decisions of their own about art. I can present, through my teaching methods, various hints and guidelines for the student to use, but ultimately it is the student who must learn to apply personality to art. In math, I must first teach students what a ratio is and how to handle ratio problems that are presented in simple form. That is thse skill building level. But to really become capable in mathematics, students must be able to take a theoretical or a word problem, and decide or discover for themselves how to apply their knowledge of ratios in order to solve the problem. This is the stage where true teaching enters in, moving a student from a skill level to a problem-solving level. For me, this problem-solving level is the goal that all courses in higher education should have.

A liberal arts graduate should be able to read and understand sufficiently to be able to pick up a text on psychological stress and understand what is means and apply it if appropriate, or read a tax manual and be able to look at a problem, read about that problem and discover how to solve it. A person who can quote Shakespeare is trained, but a person who can apply information to solving a problem, whether that problem be technical or scientific, psychological, or philosophical is educated. The person who can comprehend one of Shakespeare's situations in terms of today's world is a richer human being. Solutions may not always be obtainable in certain fields, but the drive should be toward the solution or at least toward attempting the so-

lution. I realize that this all sounds wonderfully naive, but I feel that our attitude toward what we do in the classroom is as important as the facts we teach. The goal of helping to develop individuals who think must be uppermost in our minds.

The future of education obviously depends on us as faculty. There are numerous problems that we face. One very prevalent attitude is that admission standards have declined considerably in the last twenty years. This is perhaps true and I would suggest that we do one of two things. If we accept students who are not prepared to do college work, we owe it to those students and to ourselves to provide them with the skills to succeed or fail on their own, but with reasonable time limits. Obviously, the other option is to accept only students who are prepared to do college-level work. Whatever we do, we must be prepared to bring the traditional liberal arts curriculum and education into today's job market. I think it is unacceptable to avoid facing the realities of today's world simply because we cling to some old ideal of what a true liberal arts education is. Graduating students who are able to get acceptable jobs and establish careers in the real world of work, is not somehow breaking faith with the concept of a liberal arts education. Our graduates should be able to compete for many entry level jobs on the same level as graduates with technical and/or professional degrees.

There is a great deal of discussion now about the possibility of proficiency exams in various disciplines. If we are to graduate students who have learned how to think for themselves, we need to treat them as adults. We must establish standards and apply them fairly. Treating a student as an adult means accepting that student's right to fail. At present, some faculty members knowingly or unknowingly seem to act in ways which convince students that they have a right to graduate from college simply because they have been accepted in college. I support very strongly the idea of proficiency exams and feel they should be multiply applied. For example, students should be able to show proficiency in English language usage during the Junior year. If they do not pass, they then have time for more preparation. I also feel that each major should establish field-specific proficiency exams. We would then be in a position of saying to potential employers that our graduates have x amount of field knowledge.

We are sometimes caught in a vicious cycle which perhaps is spiraling downward at present. What happens to our graduates has a great deal to do with what kind of students apply to our colleges. We obviously need to continue enrolling students to survive as colleges. If we take students who are not college material, and they somehow graduate, they do not make a very good impression on their employers and our reputation as educational institutions diminishes. If we get a bad reputation, the better students tend to go somewhere else. Therefore, our procedure must be to reverse the spiral, and produce the best students that we can. We must consider a definition of what liberal arts graduate should be, and find a way to assure that only students who fit within that definition do indeed graduate.

One of the problems with some of us in liberal arts education is that we are somehow ashamed of producing students who are able to get jobs. There is no conflict between producing a well-educated student who can perform well in the job market with the basic concept of liberal arts in general. If we are truly developing people as thinkers, they are obviously the people who should get high-status jobs. I am not here talking about knowledge somehow being its own reward, I am talking about knowledge that is brought to bear upon a topic and used to find solutions to a problem. We must be able to tell the difference in our teaching concepts between teaching a student what is fact and how to use those facts. We must also train students to discern the differences between scientific fact and scientific possibility or probability.

A question which was asked of me recently was whether a core curriculum of required courses is still a viable concept. I suspect that a core of requirements is the crucial part of what we are calling a liberal arts education. Perhaps for the future of liberal arts, this core curriculum is what we need to look at most deeply. There is obviously variety in the types

of courses we teach, or the range of courses we teach. There is some possibility that we can do better or that we do need some change, but I think that our first issue should be to look at the courses that many liberal arts colleges teach as a part of the core, that is roughly Social Studies, English, Math, Foreign Language, Science, and Physical Education, and evaluate these courses in terms of whether they meet the two goals that I've previously discussed. That is, whether we teach skills and at the same time go beyond teaching skills, to teaching content and the logical and cognitive processes that are so involved in the basis of a liberal arts education.

I think as educational institutions and as a group of well-meaning educators, we need to sit together, within our own departments or among departments, and carefully, in a non-threatening, friendly way, analyze what we are doing and see if we can do it better. Faculty morale in many institutions right now is somewhat low for a variety of reasons. One way that this morale problem can be handled is through cooperation among faculty members. I do not wish to propose an "us against them" situation but, if nothing else, when members of the faculty feel threatened by outside forces, it is perhaps an ideal time to gather together and create improvement from within. I am a faculty advocate and a student advocate. I see the solution to most problems in any collegiate situation as being a strong, unified, cooperating faculty attempting in all honesty to do the best job it can with students. There are obviously seeds of this and some real growth that have already taken place. Various curriculum reviews are a good indication of both faculty and administrative concern with what education is doing.

What I am basically suggesting is that although perhaps curriculum can be reinforced and modified, the real task facing liberal arts colleges in the future is perhaps not so much a change in curriculum but an in-depth analysis of skill building and present course content and the teaching methods we use to instill those skills and bring life to content areas. Research and committee work are obviously very important aspects of any faculty member's life. Research keeps one aware of developments in any particular field. Committee work keeps one knowledgeable about what is happening in other areas of the college and brings together people from different disciplines to solve mutual problems. But liberal arts colleges are basically schools that need strong teaching. Too often we all fall into the trap of varying our course content and our approach to that content very, very little—boring ourselves and our students and not contributing as much as possible to their development.

Occasionally administrative structures can be seen to interfere with the workings of faculty and students. There are obviously areas in which decisions must be made by administration. The administration is responsible for the smooth working of budget, admissions, dorms, etc. However, there needs to be a closer relationship between administration and faculty, a more trusting relationship that is a two-way street. Faculty members should be in a position where the burden of detail and budget and the daily necessities of running a large organization are removed so that they can concentrate on teaching. The administration, in turn, should not interfere with faculty members in the daily process of their particular activities. The relationship must be open, and must be based on trust. We should be able to communicate needs and desires effectively with both a sense of confidence that something will be done about problem areas, and with a sense of trust that our problems will be considered in good faith. Some administrative decisions must be made very quickly because of outside agencies that must be handled. But major decisions should always be made only after consultation with faculty. I think I would prefer to see change delayed rather than see things happen too quickly that are perhaps not well thought out. Consultation with faculty members as individuals and with committees should not be mere lip service. Faculty desires, committee desires, should be considered as crucial. As members of a faculty we must refuse to fall into the trap where, as it has been said, only 10% of the members of any organization really do 90% of the work. Committee work may be boring and sometimes seem pointless, but

it is important if faculty are to maintain control over our own situation. A faculty should never condone the duplication of effort by committees, and I feel that we need to provide a much clearer charge to committees. But in some institutions it is basically through committee work that we can create change for the better.

We must keep constantly in mind that a liberal arts education traditionally does one of two things: it prepares students for further study, or it prepares students to join a work world and be trained by that world. Neither should supercede the other. There is not dishonor in preparing a student in business administration or in social work for moving immediately into a career. We should not be that elitist or snobbish. However, we must not neglect students who wish to continue their studies before they join any particular profession, for example, teaching or law.

I feel that in the future, as is somewhat true today, a good liberal arts graduate will always find a job. Industry needs people who are facilitators, people who can approach a variety of problems or subjects or topics because of their strong generalist's background, and either solve a problem or bring together people who can solve problems. Obviously a key factor in being a facilitator is skill in communication on all levels. We betray our graduates if we do not help them become skilled communicators.

Probably strong liberal arts colleges will exist and perhaps become stronger regardless of all the problems with administration and faculty and curriculum changes as long as honest people are attempting to pass on what they know to a future generation, enabling that future generation to build upon the past. The role of the administration and faculty is to provide the best atmosphere and conditions for that educative process to happen. Administration should be in a supporting role to faculty and ultimately to students. The business aspects of collegiate life are important but only as a body to support the head and mind—the head and mind being faculty and students.

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The Warmed-over Debate on Undergraduate Education

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When I am not annoyed with the present form of the debate over undergraduate education, I am amused. I try to be more amused than annoyed. The amusing part is simply the observation of the follies of those who periodically rediscover undergraduates. Because some politician or some commission has raised the issue of curriculum again, all the same old debaters or their clones tear themselves away from their word processors, attend one, maybe two meetings on the subject, and get all hot about whether English

IV is more important than English III or maybe even more important than History V. What should be taught? What should be read? Is Virgil more important than Dostoyevski? Is Shakespeare more important than Hemingway? Are any of them more important than the New York Times? Is the New York Times more important than the Village Voice? And of course the word "crucial" is thrown around a lot even if no one ever means it literally. Somehow the future of society is at stake. It reminds me of Book III of *Gulliver's Travels,* which of course is "crucial" and should be required reading. My amusement is, as you can see, Swiftian.

The annoying part of this experience comes from observing how self-serving the arguments are and how little is offered of that which genuinely counts. It is not a required core curriculum which creates the academic good life, or yet any set of required courses, nor any particular list of books but our own willingness to be of help to our students. If there is a magic formula it is concocted from the following: the professional and personal commitment to teach well, to make every class a lively and intellectual experience, to spend lots of time with your students one-on-one. There is no substitute for this. I don't care what the curriculum is, if you can't leave the student with the impression that what you are teaching is interesting, fundamentally personally useful, worth thinking about, worth asking questions about, any curriculum is dead in the water. Teaching needs emphasis.

Take the notion of a lecture. It continues to astound me that here, almost at the beginning of the 21st century, five hundred years after the printing press, existing as we are in the educational era of Xerox, the lecture continues to be a primary form of instruction. The lecture was a medium that came into being when there was no moveable type, no Xerox, very few books around and those usually owned by the professor, and so the professor would impart information. Many professors still behave as if they couldn't put their lectures into a Dictaphone, have the darn thing typed up, and have it distributed to the students to read, assuming that there was anything new in the lecture that is not already given in the textbook.

Obviously I speak of the formal lecture. I am not at all saying that the professor does not have or should not have the dominant role in the classroom. The opposite extreme, the free wheeling, formless, unstructured student discussion approach is also the lazy man's approach to undergraduate teaching. The classroom should be the place where questions are discovered, material is analyzed and synthesized, where the professor is challenged to explain and explain and explain, where the student is challenged to articulate his understanding, where things not included in the information spontaneously arise and are related to the information, where the materials presented cease to be information and become intellectual experience.

This is a lot harder to do than lecture. It is a lot harder to prepare. To try to teach like this in the classroom you have to have the same dedication that an actor has to a new role, that an inventor has to the solution of a problem, that a painter has for a blank canvas. You need to prepare as much and with as much concentration as any athlete for an event. Like a gymnast you need to get a good start, run, spin, twist and land in the right place. Undergraduate teaching should involve a whole lot more than pulling your lecture notes out of the file, getting into your car, arriving at the class on time, giving your lecture, and going back home to your word processor.

Professoriat of all colleges, arise! You are wasting the minds of your students. Do you want to exalt them in their questioning? Do you want to know what books they should read so that you can suggest them? Do you want to know what courses they should take to best suit their intellect and personality? Then go to the students. Don't sit around and argue in committees! Don't posture in the academic senate! Neither the questions nor the answers are there. Spend your time with the students. Talk to them about their minds and yours. Find out where they are strong and where they are weak. Intuit their natural drift. You know what? They will, in fact, read the books that you suggest. They will, in fact, take many of the courses that you suggest. They will try on and wear for a while and keep or discard ideas that you suggest. They will get an education in spite of lecture courses,

core curriculum debates, changing fads, distributive requirements, committees and senates. Do you want the magic formula? Spend time with the students. Spend time with the students. Spend time with the students.

Try this. Pick out some small sample group of people who you think are intellectually pretty good. The farther they are from graduation the better. Pick good intellectuals who have graduated at least ten years ago. Ask them about the high points, the intellectual high points, of their undergraduate education. And don't ask professors, ask someone else. Professors never quite get over thinking in terms of curricular lists. Ask these intellectuals about their undergraduate experience and see how much of it has to do with some distributive group or other, with some core curriculum or other, with some requirement or other. In fact, all that will have long passed away. Ask them what has stayed with them over the years. Ask them about those experiences that have led them to read more and more books, or hang around various ideas. Inevitably, inescapably, you will find that the valuable and memorable experiences are related to an experience with a professor, with time spent, with conversation, with a personal exchange.

So I pay little heed to the terms of the debates about curriculum. I know that nothing particularly important will come from that tinkering. One group of professors will push their own group of courses, another group of professors will push another group of courses, they will all try to justify their jobs and their disciplines. What I worry about most is that they may be successful in imposing upon undergraduates requirements which will deflate rather than expand their curiosity.

I remember once when I was taking my undergraduate degree in Literature, I was bulldogged into taking a course involving the writing of John Milton. I really didn't feel the necessity of it. It wasn't a matter of preferring modern writers to so-called classics. I always enjoyed and still do the writing of Donne, Crashaw, and others of that general time. So I took Milton. To this day I feel that if I were on the proverbial desert island and had to choose between having the works of Milton to read or nothing at all, I would choose nothing at all. So much, in my mind, for being overly forceful in dictating a curriculum in higher education, whatever the arguments.

Some of the current objectives to free-form general education go like this: a student can earn a bachelor's degree without ever taking a course in American history, without having studied a foreign language, without having read any of the ancient classics, without having read Shakespeare, without having read Plato, or Marx. It may well be that the student has had American history out the ears in high school, prefers Tolstoy to Shakespeare, is more interested in supply-side than Marxism, and is more interested in Darwin than Marx. Who is to say that these are the wrong choices?

To be sure, we want to know that our students are learning and learning and learning. Otherwise why should they be wasting their time and money in college. But we are fooling ourselves if we think that the value of their education is in a prescribed curriculum. I am talking about their general education. It is obvious that pursuing professions and specializations does require a logical plan. In chemistry certain things have to be learned before other things are learned. In mathematics, the same. In accounting, econometrics, biology, the same: certain things have to be learned before other things are learned. But insofar as the rest of a student's education is concerned there are two things we can do: 1) stay out of the way and do no harm; 2) get in the way and do a lot of good. The latter is accomplished by giving a good class, spotting interest and curiosity, spending time with the students, tuning into them and getting them to tune into you. That's where we do our work as professors. Required curricula don't do our work for us. The recurrent debates about curricula are a side show.

What then should an undergraduate education be? What will make the time, the money, and the effort worthwhile? Is there an outline of a good education that does *not* make an undergraduate education something like buying one of those canvases on which the lines are all drawn out and you paint in the landscape with colors that are indicated by the

numbers. I think yes. This is my approach. This is what I tell my undergraduates.

1) Learn to write well. Learn to make yourself clear, concise, and specific. Know what a paragraph is and how to use it. Know how to arrange information and present it. Know how to take a sentence apart and put it back together. Know how to explain what you mean. I am not talking about fancy writing. I am not talking about creative self expression, the results of which are often that neither you nor anyone else understands what you expressed. Learn how to be clear, specific, to the point. Learn how to write in such a way that no one is vague about what you mean.

In one of the reports (*Involvement in Learning*, National Institute of Education) often cited in the current debate on higher education, I read the following passage: "Faculty and academic deans should design and implement a systematic program to assess the knowledge, capacities, and skills developed in students by academic and co-curricular programs." This is the kind of writing you should NOT learn, let alone the kind of writing that should be done by somebody commenting on American higher education. What the writer probably means to say is that we should devise a way to figure out what our students are actually learning. He or she should have said that. Do not write like this. Learn to write simply and clearly. This is the absolute priority. It is an intellectual priority, because if you cannot explain it well, you cannot understand it and your readers won't either. It is also a practical priority, I know of no single factor which will more guarantee success, plain old promotional, salary-raising, status-climbing success.

2) Take a double major, and major in two things which are unrelated. Let one of the majors reflect what you think you might want to do for a living. In some cases, you already know. You have decided to major in electrical engineering, mechanical engineering, accounting, or the like. If you are not sure what you want to do for a living, pick out a major that involves those things you think you like hanging around, those things which seem now of working interest to you. If you are interested in buying, selling, marketing, money, you might choose business administration or economics. If you like hanging around laboratories and doing things with your hands, you might choose chemistry, biology, physics, whichever seems best. If you know you want to work with words, pictures, information and its dissemination, you might major in journalism. In any case, let your major be the one which studies the mental stuff you might want to spend the rest of your life hanging around.

Then pick another major that has absolutely nothing to do with any job you think you may ever have. Let it be unrelated to the first major. But let it be something you love in and of and for itself. Let it be something you want to spend the rest of your life hanging around when you're not working. My idea of sensible paired majors runs something like this: business administration and philosophy; economics and art history; pre-med and music; public administration and studio art; chemistry and literature; government and dance. If you do this, you will have one major which gives you vocational direction although it will not give you a vocation all by itself, and one major which belongs only and soley to you and your own personal internal life.

3) If you do not already know how to do it, learn to use a computer. Learn to put your hands on it, put information in, take information out, do some basic programming. It is the nature of the world we live in that this will be both professionally and personally useful to you almost no matter what you do. Whatever your job in the future will be, I guarantee you that somehow or other you will have to know about this. For your personal life, you will not be able to avoid in the future all the many things in every-day life, information retrieval, public communications, video and audio entertainment, that will be linked up with the computer. Even your interests in music, drama, art, philosophy, and literature will be in one way or another in the future enhanced by what you will be able to do with the machine and with all the resources that the machine will be hooked up to.

4) If you can hack it, learn one modern

foreign language well. I mean well. Learn it to a degree of good, perhaps very good, competence. I do not mean simply to take a course or two, I mean learn the language well. This is a key to innumerable things, including the culture that the language represents, other languages, the acrobatics of expression which you gain by knowing two languages and developing a flair in linguistic skill. It might even be a very marketable commodity.

Connected with this, if it can fit your schedule, see if you can study abroad for at least one semester in the country of the language that you are learning. The value of the experience of living and studying in a foreign country during the course of your education is obvious.

5) To the extent that you have electives left, follow the questions which interest you most. If you are intrigued by, say, whether or not Reagan will some day be considered a good or bad president, take courses in American history or American government. If you are confounded and upset by the debate on abortion, study philosophy and biology; if you want to know how things work, satellites, fiber optics, space shuttle, the telephone system, take physics; if you want to know why you should some day read novels rather than not read them, or what a poem is, or how writers synthesize the form and substance of their times, take literature courses; if you are fascinated by the phenomenon of terrorism, take some combination of the following, 19th century European political movements, Russian history, abnormal behavior, and ethics. If you happen to be majoring in chemistry but you are interested to know how a bank works, find the course and take it. If you are majoring in banking but you are interested in the substances which we ingest accidentally, deliberately, or environmentally, take chemistry, biology, and toxicology.

The main point is that the intellectual world is wide. It is wider than you are. So develop the questions that naturally come to you. Sharpen them. Let them grow. Let them change form, shape, and wording. And study those things which will surround the questions.

That is what I tell my students. "Learn. Learn. Enjoy. Enjoy." Ultimately the quality of education will depend on the quality of the teaching, on good lively classes devoid of drone and boredom, on generating questions, on the confrontation of ideas, on the explanations and similies and analogies and suggestions of the professors. It will depend on learning to write well, on a solid major or, better, two solid majors, on understanding the informational technology of the times, on getting to know the rest of the world and how it works. It does not depend on this core curriculum or that. It certainly does not depend on how the present debate turns out or the wasteful expenditure of time and energy that the debate will consume. Ask anybody who is smart and has been to college . . . except educators, administrators, and bureaucrats.

Journal of the Washington Academy of Sciences,
Volume 75, Number 1, March 1985

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Is the Notion of a Just War Applicable to Nuclear Deterrence (Nude)? (An Evolutionary Argument for the Nudist Camp)

G. L. Farre (1985)

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A number of people who have taken an anti-NUDIST stance have justified it in terms of the Just War Tradition (or Theory), on the grounds that

a. Nuclear War is irredeemably evil
b. The threat of an irredeemably evil act (ie NUDE) is itself an irredeemably evil act.

I want to argue that the Just War Tradition (JWT for short) fails to provide suitable grounds for predicating evil of NUDE, mostly because it is inapplicable in the circumstances in which the question of NUDE arises.

I will begin with an analysis of the notion of NUDE, then follow up with a list of the main features of the JWT which are relevant to the argument. I will then conclude with a brief examination of whether the latter has any bearing on the former.

(I) NUDE

The purpose of this section is to introduce a number of needed notions. The key ones are that of an organism, that of a nuclear society as a particular kind of organism, and that of nuclear deterrence as self preservation of that kind of organism.

(A) *On the Notion of Organism*

1. An *organism* is a complex characterised by a structure used for the acquisition, the processing and the diffusion of information, that is a *Central Information System* (*CIS*). For present purposes, we may consider that this structure forms the essential element of the criterion of identity for the organism, and gives point to what is meant here by its *integrity*.

2. The *survival* of an organism means the continued applicability of the same criterion of identity throughout. In no case can the survival of the organism be thought of as independent of that of its CIS: in particular, the independent survival of its parts and components is not to be equated with the survival of the complex.

3. An important characteristic of an or-

ganism is what may be called its *Binding Energy* (*BE*), which is normally distributed over its elements. This energy is provided by a corresponding proportional loss of autonomy and perhaps even by a partial loss of integrity of the elements of the complex.

The appearance of such constraints as are indicative of the BE marks the emergence of a higher organism, i.e. an organism more complex than the ones being constrained. Due to the structuring of the higher organism, these constraints affect the relations between its elements, thereby dividing its world into *internal* and *external* parts, that is with two distinct environments and, by way of consequence, with two distinct modes of adaptation and therefore of definition.

4. These constraints, which bind the components together into a single whole, provide a suitable basis for understanding (i.e. for constructing a model of) the natural (i.e. inherent) values embedded in it. These values define what is good behavior for the components of the whole, and thus what is not as well. It gives content to the notion of the *integrity of the organism*. The preservation of this integrity may be defined as the ultimate value of the organism, in the sense that the destruction of this integrity and that of the organism come to the same thing: death as an identifiable and viable entity.

The integrity of an organism may be threatened either internally or externally. In any viable organism, there will naturally be found internal mechanisms of defense and others that are turned toward external threats.

(*B*) *Human Society as Organism*

5. In the case of a human society, the BE takes the form of the *culture*, the principal manifestation of which is the *language* in which it finds its expression, and more specifically, the *conceptual framework* that it reveals.

This means, among other things, that the rules governing the behavior of a human society viewed as a whole in a context external to it are likely to be very different from those governing that of its component parts (e.g. individuals and groups which are internal to it).

(a) Such differentiated patterns of behavior are quite general, and can be used to gauge the strength of the bond keeping an organism together. In the case of competing human societies, the cultural character of the bond is used to justify various forms of cultural warfare (e.g. control of information, of its origination and of its diffusion, disinformation campaigns, propaganda, etc)

In particular, the internal mechanisms of defense are different from the external ones, a circumstances particularly obvious in the case of nuclear states.

(b) We may also expect the behavior of a given society to be radically different, depending on whether it is dealing with another society that shares similar values or not, even though the language be somewhat different. In particular, in conflicts in which values are seen to be threatened, we may expect to see the behavior of the endangered society reflect both the nature of the threat and the relative importance of the values perceived as challenged. At the limit, the conflict will take the form of a fight to the death with no quarters given. At the other end of the spectrum, in conflicts in which the values of a given society are not threatened, we may expect to find those forms of behavior which reflect its traditional cultural attitude (e.g. Just War Theories).

6. The cultural nature of the criterion of identity for human organisms, such as nations, links in an essential way its perception of what is possible to its means of analysis and therefore of action. We may therefore expect a human society to have a tolerably serviceable understanding of itself in the context of its environment, a vision that is deeply cultural. As the culture of a given society evolves, for example through an increase in knowledge or through the development of new technologies, so will the culture sensitive view it has of itself and of its world, and so will its behavior.

7. The study of nuclear societies (*NUCSO*) reveals that their behavior is markedly different from that of non nuclear societies, not only relative to each other but also internally (e.g. managing nuclear power, nuclear pollution, nuclear weaponry, etc.) So much so

that NUCSOs may be thought of for most purposes as members of a more evolved species than that to which a conventional society (*CONSO*) belongs.

(C) On the Notion of Deterrence

8. The idea of the deterrence of B by A reveals on analysis five main elements:

a. the ability of both A and B to describe different worlds
b. their ability to perceive some of them as possible, that is as accessible from the actual world W
c. the perception by B that the path leading form the actual world to a set of possible worlds for B is accessible directly by A, or even that such access is exclusively in the hands of deterring agent A.
d. Among the possible worlds of B accessible to A is a set of unacceptable ones W*(B), and among those accessible to B are possible worlds of A unacceptable to A W*(A), thereby creating a mutual dependence for the worst.
e. A is credible to B, i.e. B knows, or has grounds to believe that A will access W*(B) if B accesses a possible world of A W*(A) which is unacceptable to A.

9. The credibility, which is so essential to deterrence, is borne of history, what the agent has done in the past, how he views similar problems and how he approaches them, how he ranks the different possible worlds available to him (i.e. life is not worth living under certain circumstances, etc), all cultural traits.

10. The ultimate element in deterrence is the realisation by the party to be deterred (i.e. B), that it has it in its own power to initiate the path that leads to the worst of all possible worlds for it (namely its non survivability as an organism, with its own cultural integrity intact). This is best achieved by making the origin of the path leading to W*(A) identical to that of the path leading to W*(B), thereby insuring maximum credibility: for then it is possible for B to be effectively dissuaded from any course of action that would mean the initiation of a path leading *inexorably* to unacceptable damages to his own integrity and autonomy.

So what deterrence means, in fact, is that the deterring party surrenders the power of decision to its opponent by linking its own fate irrevocably to that of its opponent. It is a form of resistance which differs from the "turning the other cheek" theory in only this, that it does not provide incentives to the prospective aggressor to go through with its aggression.

(D) NUDISM as the Only Way of Life

11. NUDISM is the only way of preserving the integrity of the organism and this for two reasons. One is that the conflict between the super powers is an essentially ideological one. The second is that the super powers are also NUCSOs, a circumstance which affects the context in which the conflict is to be seen.

12. Nuclear Weapons (*NUKES*) strip the social organism (ie society) of its cultural determinations, and reduce it to the Lowest Cultural Denominator, namely that of the bare biological life of the members of NUCSO (e.g. "bombing them back to the Stone Age").

13. NUKES therefore gut out the idea of preserving cultural integrity in the process of the conflict, while stripping the opponent of his, which is what an ideological conflict is all about. They spell out the destruction of the foundations of cultural identity.

14. Thus the suicidal character of NUDE imposes new constraints on the members of the group of NUCSOs marking therewith the emergence of a new kind of global society, that of the *NUCHAVES* (*Nuclear Haves*). The process thus appears to follow a completely natural pattern, raising the question of the appropriateness of moral predicates to characterise it.

(II) On the Notion of a Just War

1. Two main components: *jus ad bellum* (has its origins primarily in theological and clerical circles) and *jus in bello* (which has its origins in military and legal (government) circles).

2. The *jus ad bellum* (the right to make war) eventually came to incorporate the following elements:

—just cause
—right authority
—proportionality (that war should do more good than harm)
—last resort
—purpose is the achievement of peace

3. The *jus in bello* (law of war). Two main principles:

—discrimination (avoid harm to non-combatants)
—proportionality (banning certain kinds of weapons, etc)

4. Two main aspects of this concept of Just War: formal and applied.

5. The formal aspect is the result of the enmeshement of the term is a conceptual framework (COFRA) that is characteristic of the culture of a particular society at a particular time and place; i.e. it is culture sensitive. The term itself, like all concepts, will in fact mean different things to different people at different times and places.

6. The practical aspect results from the application of a principle of intelligibility to the elements of the domain in order to make sense out of it. The viability of the formal aspects is dependent on their "meshing in" with the other perceived features of the domain (ie the real world), since the urgency of practical problems often forces the decision makers to resolve apparent inconsistencies in the perceived fabric of sensicality.

7. An important feature of the formal concept of a just war is not apparent in the enumeration of elements of the *jus ad bellum* component of the just war tradition, but is revealed by its history, and especially that part which relates to the history of its applications, i.e. what has counted as a just war. What appear are two things. One, that the elements of *jus ad bellum* are not equally weighted, a just cause being on occasion counted as sufficient to overrule the other elements, unless we wish to regard it as incorporating the other elements at least implicitely. It seems that ideological wars tend to be of this nature (eg. holy wars). Second, this may go to the extent where the doctrine of *jus ad bello* itself becomes caducous, justifying in the prosecution of such wars a degree and a scope of violence characteristic of the modern total wars.

8. The Just War Theroy is inescapably culture bound. This means a number of things. First, given the rapid development of culture in the last four hundred years, and the present acceleration of the pace of this historical process, there results within a given society a cultural gradient generated by the difference between what may be called the *sources* and the *sinks* of information, in particular by the time lag between the generation of new information by some and its diffusion and absorption by others in the rest of society. We may expect this lag to be greater where the cultural differences are already more pronounced (e.g. levels of education, awareness of the evolution of thought, etc.)

9. It also means that the information transfer, slow as it may be in some cases, presupposes a certain amount of cultural unity among the members of that society: they share a language, and not simply words. The language, which is the mark of cultural unity within a society, is also a mark of cultural differentiation between different societies. So we may also expect to find a cultural gradient on a more global scale, an important consideration when attending to matters of international character, especially those relating to war.

10. The international cultural gradient is of various steepness going gradually from the minimal to the abyssal. In the latter case the amount of possible cultural transfer in time of crisis is minimal, barring a sudden conversion.

(III) JWT: Not a Good Anti-NUDIST Argument

1. Two sets of considerations, depending on whether the threat to the integrity of NUKSO and its CIS is external or internal.

2. Internal considerations: cultural diversity is an essential ingredient of the fabric of the Western Democracies, and forms a part of the integrity of our culture. The notion of JWT does not accomodate the preservation of this cultural diversity when cultural values are themselves in question (historically, toleration is born of diversity). In the case of the East–West conflict this very cultural diversity is what is threatened.

3. External considerations: The conflict with states of marxist obedience is ideological, at stake is a different conception of man, of nature and of man's role in it. It is perceived as a militant universalist ideology, essentially inimical to our own ideology.

Evolutionary view of nature means that the future does not resemble the past. The wars engaged in by Western countries have, with a few exceptions, been progressively ideological, rather than territorial, dynastic or economic. The parallel therefore, is more with wars of religion, which were ideological, than it is with those in which some other issue was at stake, such as territory, successions, etc.

The JWT was not meant to apply to ideological wars without some profound modifications, the just cause by itself making caducous the *jus in bello* restraints. A society, as a culturally defined entity is fighting for its life when it is fighting for its cultural identity.

4. NUDISM is not an advocacy of war in any of its classical senses (e.g. as policy conducted by other means). It is not a means of furthering policy, but one for the survival of one's cultural identity, and thus of one's integrity which is being threatened. In our Western community, we have long passed the stage where simple and unadorned biological life was *the* supreme value, for us the life of the person is not to be confused with that of the biological organism which sustains it, and we have long accustomed ourselves to the sacrificing of the latter for the sake of the former. Our culture has evolved, through many vicissitudes, to the point where our society has become, in essence, one of free men, the freedom of each individual being the value for the sake of which this and similar societies have been created. The birthing revolutions here as in France and elsewhere, were seen as intrinsically just conflicts. NUDE is justified on the same grounds and so would the use of NUKES in the defense of the same values.

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"Are Personal Computers Necessary for Use in the Home"

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Washington, D.C. 20057

For most of us, personal computers are not only not necessary, they are not even desirable for use in the home. A personal computer in the home should be viewed as another household appliance. To determine whether any appliance is worth getting you should ask:

a. What will it do for you?,
b. What will you have to do to be able to use it?,
c. How much will it cost?, and
d. All-in-all, is it worth it?

The answers to these questions are:

a. A handful of useful things,
b. a great deal,
c. at least several hundred dollars and as much as several thousand dollars, and
d. no, unless you do a great deal of writing at home or you are addicted to the games that you can play on a computer or the fun of writing computer programs.

The remainder of this paper is divided into five sections. The first two provide a more detailed answer to the questions: What will a home computer do for you? and, What will you have to do for the computer? The last three sections contain the answers to the following questions:

1. How has the introduction of a home computer affected household activities?
2. Is there a special reason for scientists to have a computer at home?
3. What about the desirability of having a computer in the home in the future?

What Will It Do For You?

As a household appliance, a personal computer can be used as a toy, an educational device, a word processor and for such household activities as maintaining financial records, maintaining an inventory of household items, and storing and retrieving recipes.

Closer examination of the last category—helping in a variety of household activities—indicates that either the activity is effectively handled now (through such mechanisms as a checking account or a card file) or it probably isn't worth doing. Moreover, as we shall see in the next section, almost any household activity to which we might apply the computer would require too much data entry to make it worth doing. This leaves the handful of applications of its use as a toy, an educational device or for word processing.

The value of a computer as a toy is a matter of personal preferences. There are some people who enjoy playing computer games or writing computer programs so much that to them a computer is the ultimate toy and well

worth owning. For the rest of us, the computer is a tool not a toy. However, if you are addicted to playing games on a computer or to writing and executing your own computer programs, you need read no further. For you the home computer is a necessity.

What about the value of the computer as an educational tool? Television commercials seem to emphasize this application. Students doing their homework, youngsters learning to spell and everyone learning how to write computer programs are often shown in these commercials. Unfortunately, this use of the computer is oversold. Schools that use the computer as an educational aid have a computer available to the students for this purpose. If the curriculum assumes no access to a computer, students that do use the computer as an aid in such things as carrying out arithmetic calculations or in learning how to spell may fail to learn what they are supposed to be learning. Students should do the homework as assigned if they are to get the most from their schooling.

Home computers can be helpful in getting people to learn how to write computer programs. Beginning levels of this skill can be self-taught. However, experience in computer courses with programmers who were self-taught indicates that such programmers frequently develop bad habits. They write unnecessarily complex programs. This is usually because they have mastered only a few programming techniques and attempt to apply them in places where other techniques could be more easily applied. Although you can teach yourself programming at a beginning level on a home computer you had better take some courses in programming if you wish to progress beyond this level.

Finally what about computers as a writing aid? Word processors facilitate the drafting and editing of written products. If you record your written product by keying (for example by typing it) then a word processor is a very useful tool. It permits you to organize your thoughts, build a written product piecemeal, correct and edit the product extensively, and even may provide such things as a spelling checker and a simple-minded grammar checker. All of these are helpful. Anyone who writes extensively at home should get a home computer with a good printer and a family of good word-processing programs. This will cost thousands (not hundreds) of dollars but the investment is worthwhile if you do a great deal of writing at home.

What Will You Do For It?

The two principle problems with the use of the computer in the home both arise from the fact that computers are very stupid. First, they do not know how to do what you want them to do until they are told how. (This is the purpose of computer programs—the computer software.) Second, the principle way to get information into a home computer is by keying it in character by character.

Consider a possible household application of a computer: storing and retrieving recipes. There are computer programs available for setting up a file of this kind and for retrieving information from it. You would probably not have to write such a program. But you will have to tailor what you would like to do to the program that is available at the price you are willing to pay. This may result in your doing such things as placing an upper limit on the length of your recipes that is sometimes too short or limiting the way you might classify and retrieve your recipes to just one or two or three variables of classification.

This last restriction may be very important. Suppose you wish to be able to retrieve your recipes based on a wide variety of classifications. For example:

a. Geographic or ethnic type (eg.—Chinese or Italian or French),
b. principle food ingredient (eg.—fish or fowl or potato),
c. spice category (eg.—hot or mild or bland),
d. meal (eg.—breakfast or lunch or dinner or snack),
e. caloric content (number of calories),
f. cooking method (eg.—stir fry or broil or barbecue), and so on.

The computer program should permit you to enter this information with each recipe and

to do such things as retrieve all recipes that are in a given combination of classifications. Programs that do this for a long list of possible classifications are more expensive and more difficult to use than those that do it for a short list. Moreover, the longer the list the greater the likelihood that the program will be difficult to use. Figuring out how to use the program to do the job may be a difficult and time consuming task in itself.

Let's assume you have the right program and you have also figured out how to use it. Now you must key in all the recipes along with all the classifications of each recipe character by character. Adding a clever color coding along the upper edge of your recipe card file would almost certainly be much easier to set up and would probably be just as effective.

By now you may be convinced that trying to apply computers to household activities is much more work than it is worth. If you are still not convinced, you should read an article that appeared recently in the Washington Post Magazine (1).

How has it Affected Household Activities?

Does the presence of a computer in the home affect the activity of the members of the household? If so, how are these activities changed?

A systematic study was undertaken to answer these questions. The methodology used and the results obtained are presented in detail in an article in the Communications of the Association for Computing Machinery(2). The principle findings are summarized here. These findings are based on a survey of 282 households that used home computers.

Major changes in the time members of the household devoted to various activities did occur after the introduction of a home computer. Time spent on the following activities decreased: watching television, pursuing hobbies, outdoor recreation, sleeping and leisure time with the family. Whereas time spent alone and on studying increased.

The magnitude of the changes varied with age. Greater changes occurred in persons between 26 and 55 years of age.

Some changes were effected by other demographic variables. For example, people with higher incomes and married people reported a greater decrease in television watching than persons with lower incomes or persons who were unmarried. Also, families with one child reported greater changes than either households with no children or those with two children. However, households with three or more children had patterns of change more like those with one child.

Evidently users with no previous computer experience were spending more time with their computers than persons with previous computer experience. Are they learning or does this reflect a burst of initial enthusiasm that wears off? The survey could not answer this question.

One final note regarding the households in the survey. They had above average educational levels and incomes and tended to be engaged in technical professions. That is, they are more like you, the readers of this publication, than they are like the public at large. This would imply that the results reported in the article are highly likely to be applicable to your own experience.

What About Scientists and Home Computers?

Are there special considerations that might apply to the readers of this publication—Washington area scientists? We have already noted that the survey discussed in the previous section is more likely to be applicable to you than to the public at large. What about the basic issue itself: the necessity for a home computer?

More writing is probably done at home by scientists than by the "average person". If enough writing is done at home then, as we have already noted, a home computer is a valuable tool. But what about such things as creating and exploring models, carrying out statistical calculations and tests and, for those of us who teach, preparing lecture materials

and homework assignments? Computers are certainly useful assistants in these and other scientific activities. But nearly all of us have access to a computer facility that is larger and faster than a home computer. These other facilities also have a more extensive repertoire of programs, may be directly linked to experimental equipment and computer networks and may have special output devices to do such things as prepare graphs. In short these other facilities are better. But they must be shared with others.

The principle special consideration that might induce scientists to get a home computer is that it is always available. (However, your family may have other ideas about the priority of its use.) This means that a personal computer in the home might serve as an effective supplement to the other computer facilities that we use. But:

a. It is frequently the case that programs that run on these other facilities will not run on your home computer, or
b. data are stored in a medium or in a format on these other facilities that is incompatible with the medium or format required at home, or
c. the computer at home is too slow or insufficiently versatile to get what you are accustomed to getting from the use of a computer.

In short, if you wish to get a computer of your own to supplement computer facilities you have available at work or elsewhere be sure you select one that is highly compatible with these other facilities.

What of the Future?

Computers are getting smaller, faster and less expensive. Programs are being written to make them both more useful and easier to use. For example, voice output from a personal computer is now possible and voice input is being developed. These improvements will undoubtedly result in a greater and greater likelihood that the answers to the original questions will be that there are lots of things you can do with a home computer, it is easy to use and very inexpensive and so, of course, it is well worth buying. Right now, however, these are not the answers to these questions. Except for a few special applications, personal computers are not necessary or even desirable for use in the home.

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On Galileo and Statics*

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Whenever I re-read or re-view Galileo's writings, I am always pleasantly surprised to discover that I continue to enjoy them. I find myself apparently understanding so many of his ideas that he seems to belong to our modern age rather than to an earlier one. He illuminates whatever he touches, even ancient mechanics; he excites the common reader with his comments about new material. He is a good example of serendipity in action. Thus the urbane Venetian Giovan Francesco Sagredo is made to remark, "If, by digressions, we can reach new truth, what harm is there in making one now, so that we may not lose this knowledge, remembering that such an opportunity once omitted, may not return; remembering also that we are not tied down to a fixed and brief period but that we meet solely for our own entertainment? Indeed, who knows but that we may thus frequently discover something more interesting and beautiful than the solution originally sought?"[1a] I am every grateful that Galileo had a genuine desire to communicate his findings and understandings.

In the opening scene of "The Life of Galileo," Bertholt Brecht appropriately has Galileo inform the ten-year old Andrea, "When a young man in Siena, I saw how a couple of builders, after five minutes argument, replaced a thousand-year old system for moving granite blocks by a new and more practical arrangement of the tackle. Then and there I knew the old age is past and a new age is here . . . What is written in the old books no longer satisfies them."[2] Galileo sounds sincere when he concludes the fifth chapter of his early essay (unpublished) "On Motion" with the admission, "My aim is a richer comprehension of the matters under discussion, and a more precise understanding on the part of my readers.[3a]

Even though I am concerned here today primarily with the statics of Galileo, in order to understand any phase of his activity, I believe, it is always necessary to regard him in his totality, as an integral person[4]—not merely as an astronomer or as a mathematician, or even as a churchman, et al. Mechanics, for example, is a thread that runs throughout his entire life's work—from his early writings, "La Bilancetta" (1586), "De Moto" (ca. 1590), and "Le Meccaniche" (ca. 1600), to his final publication in 1638 of the "Discorsi e dimostrazioni matematiche intorno à due nuove Scienze." Throughout this span of 52 years statics emerges again and again! Even in this familiar subject we find Galileo often misunderstood. Yet, as an American scholar, Ralph Waldo Emerson, notes in his essay on "Self Reliance" (1841), "Is it so bad then to be misunderstood? Pythagoras was misunderstood, and Socrates, and Jesus, and Luther, and Copernicus, and Galileo, and Newton, and every pure and wise spirit that ever took flesh. To be great is to be misunderstood."[5]

*Invited address, Galileo Quatercentenary Congress, Notre Dame University.

There is a particular merit, I suggest, in having complementary re-views of physics by physicists. In the first place, a present-day physicist has the vantage point of nature itself. Uncertainties with respect to unknown sources, to unspecified references in them and to missing links of communication among them, are well-known historical difficulties. The physicist, however, does have a unique advantage, namely, the so-called uniformity of nature, which being the same yesterday and today can still be checked as to phenomenological statements. Nature itself is a primary source of "historical" information, our rightful material heritage—not only secondhand book learning. From a humanistic point of view "the principal forbears of modern science were in fact the twin traditions of Greek philosophy and mathematics,"[6a] but we must not forget "mother nature", the ancestress of such studies then and now.

Secondly, professional physicists have the unique vantage point of the ever-changing present. It is not sufficient, though necessary, to stand where Galileo once stood and to look back at his precursors. We must also look forward to his postcursors. We must be concerned with all historical material; not only that for which Galileo is indebted, but also for that which succeeding generations are indebted to Galileo. The continuity of history extends in two directions, both past and future. From the viewpoint of the present, indeed, we gain a significant outlook provided by our progressive understanding of phenomena, our cumulative experience, our scientific heritage.

As we re-view today the statics of Galileo from these two vantage points of nature and of the present (supplementary to the careful analysis of the precursors by others), we shall focus our attention specifically upon three aspects: machines, hydrostatics, and the strength of materials.

We shall not, of course, attempt to cover all phases of machines, but merely to glance at some which are still critically significant today, namely, the lever, the inclined plane, and the principle of virtual velocities. Let us start with the lever (the balance), which appears again and again throughout his works (cf. "The Little Balance," "On Motion," "On Bodies in Water," and "Two New Sciences.")

First of all, let us not consider Galileo's attitude from a general Aristotelian viewpoint. What is important is not merely where one stands but the direction in which one is looking. According to the followers of Aristotle (384–322), to be sure, "As the weight moved is to the weight moving it, so, inversely, is the length of the arm bearing the weight to the length of the arm nearer to the power."[7a] A subsequent statement, however, reads, "A longer radius describes a larger circle;"[7b] hence, the metaphysical claim at the beginning, "The original cause of all such phenomena is the circle."[7c] Whereas the above descriptive rule for the equilibrium of a lever is certainly adequate for everyday use; this particular explanatory view is not pregnant with productive ideas.

Galileo's own approach to the lever is more like that of Archimedes, (ca. 287–212), the founder of statics. His geometrical proof,[1c] though different in a minor detail from that of Archimedes,[8a] is of the same general nature. Archimedes considers a symmetrical lever balanced about a fulcrum F (cf. Fig. 1a); he assumes "Aristotle's axiom (also that of Archimedes), that equal weights (2W) at equal distances (2a) from the fulcrum were in equilibrium"[9a]—on the basis of a Whittaker[17] postulate of impotence, which I shall call here

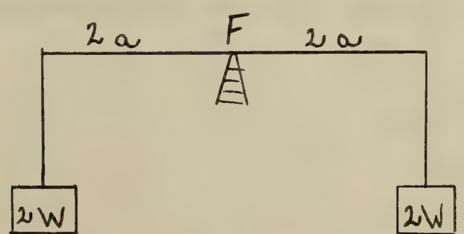

Fig. 1a

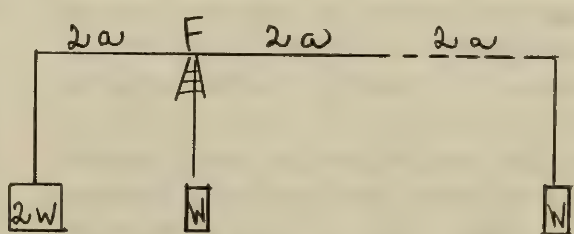

Fig. 1b

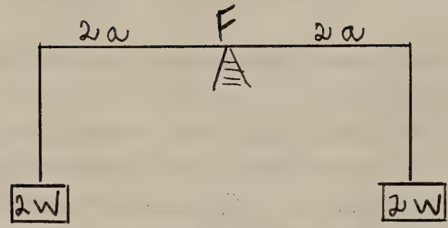

Fig. 2a

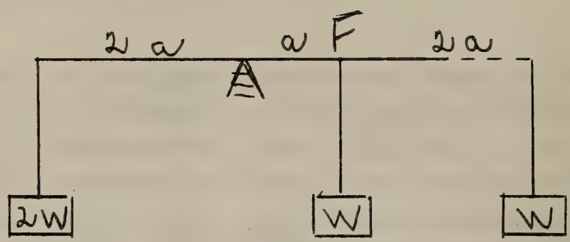

Fig. 2b

the Principle of No Sufficient Reason. He proceeds to divide one of the weights 2W into two equal parts W, which are then displaced symmetrically so that one of them appears at the fulcrum F (cf. Fig. 1b) and the other at a distance 4a away from it. Ernst Mach[10a] has indicated the logical error at this juncture of the proof. Such a displacement can be made only if the phenomena have a linear character.

Galileo, too, starts with two weights (2W) placed symmetrically (2a) about a fulcrum F (cf. Fig. 2a). In this case, if the phenomenon is linear, then the moments of force are given as follows:

for Fig. 2a

$$2W \cdot 2a = 2W \cdot 2a$$

and for Fig. 2b

$$2W \cdot 2a = W \cdot a + W \cdot 3a.$$

On the other hand, if the relationship is not linear, but of the second degree, say, then we have the following situation:

for Fig. 2a

$$2W\,(2a)^2 = 2W\,(2a)^2,$$

but for Fig. 2b

$$2W\,(2a)^2 \neq W\,(a)^2 + W\,(3a)^2.$$

Evidently equilibrium will not be maintained for such a nonlinear relationship.

In physical proofs one may be concerned not merely with mathematical operations, but also with assumptions involved in physical displacement. In the latter case success results sometimes without awareness as to the underlying assumptions. For example, one may unknowingly choose linearity out of familiar experiences. I certainly cannot subscribe wholly to the dictum in a recent history of science that "we shall not go into the question whether the proof [Archimedes] reproduced above is really valid . . . It is at all events extremely ingenious and it was of great importance for the history of mechanics."[11] From the long-range point of view man is concerned also with the validity of a principle, as well as with its mathematical role in sociological development.

What's in a name? At times, nothing! In trying to understand, however, what has been written long ago in an unfamiliar language a name may be all important. The word "momento," for example, is precisely one that caused considerable confusion even in Galileo's own time. Both the late Professor Henry Crew and Stillman Drake[3b], indeed, have found it necessary to remark on the haziness of the word as used by Galileo himself. (As far as I can tell, he never used it in the strict sense of modern momentum.) Galileo, himself, made certain to define it in the second edition of his "On Bodies in Water": "Moment, amongst mechanicians signifies that virtue, that force, or that efficacy, with which the mover moves, and the movable resists. Which virtue depends not only on the simple gravity, but on the velocity of the motion, and on the diverse inclinations of the spaces along which the motion is made."[12a] He goes on to call attention to a similar connotation of the word in the statement, "This is a weighty business."[12a] Likewise, today we still say, "It is of great moment"—meaning of great importance.

In general, we shall here interpret the word "momento" in the subsequent connotation of torque, i.e., moment of force (i.e., importance of force—in rotation). In this connection, however, we must differentiate sharply

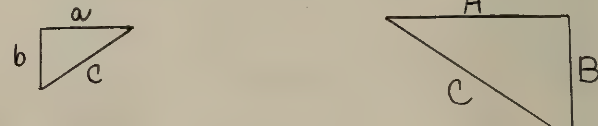

Fig. 3

between purely geometrical reasoning and "intuitive" physical experience. To illustrate the former, consider two similar triangles (Fig. 3).

For corresponding sides

$$\frac{A}{a} = \frac{C}{c}. \qquad (1)$$

Hence $$Ac = aC. \qquad (1a)$$

This expression, viz., the product of a pair of non-corresponding sides of similar triangles is a constant. Do you recognize this important rule which is as familiar as Pythagoras' theorem? Of course not! No one presumably has ever used such a relationship ab initio. The mere existence of a proportionality is no guarantee that the potential product itself will be regarded as significant. Proportionality does not insure usefulness or importance, or even familiarity.

Turning now to the formulation of machine experience, we find the intellectual Florentine Filippo Salviati insisting, "I shall take for granted the well-known mechanical principle which has been shown to govern the behavior of a bar, which we call the lever, namely, that the force bears to the resistance the inverse ratio of the distances which separate the fulcrum from the force and resistance separately."[1c] Thus we have for an effort E (Fig. 4a) at a distance a from the fulcrum F and for a load L at a distance A

$$\frac{E}{L} = \frac{A}{a}, \qquad (2)$$

but not directly the product

$$Ea = L\,A. \qquad (2a)$$

There is no evidence that Galileo or his predecessors, Archimedes, Jordanus Nemorarius (ca. 1220) or even Leonardo da Vinci, (1452–1519), used the product itself either as a distinct mathematical concept or as a physical measure of turning power. The fact that one may have a "potential arm," which is not at right angles to the direction of gravity, was recognized clearly by both Jordanus and Leonardo. The full understanding of torque, to be sure, was not achieved until the investigations (1834) of Louis Poinsot (1777–1859).

Now why was the lever (or balance) regarded by everyone so highly? The principle of the lever was considered fundamental. Thus the peripatetic philosopher Simplicio quickly reminds the group, "This was demonstrated first of all by Aristotle [or his school] in his 'Mechanics'". To which Salviati replies, "Yes, I am willing to concede him priority in point of time; but as regards rigor of demonstration, the first place must be given to Archimedes, since upon a single proposition proved in his book on 'Equilibrium' depends not only the law of the lever, but also those of most other mechanical devices."[1c] It is noteworthy that in the book "On Mechanics," after the above proof of the lever, Galileo presents also another point of view.[3c] In the case of the displaced balance (Fig. 4b) the similarity of the triangles gives for the arcs (c and C)

$$\frac{A}{a} = \frac{C}{c}.$$

Substituting in equation (2) we obtain

$$\frac{E}{L} = \frac{C}{c}. \qquad (3)$$

Hence Galileo had rightly concluded that in a given time, "The speed of motion of the heavy body B (E) in descending comes to be

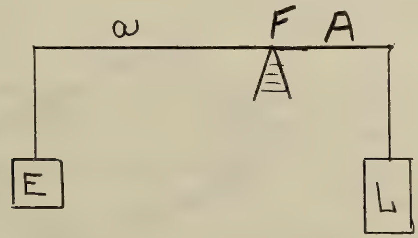

Fig. 4a

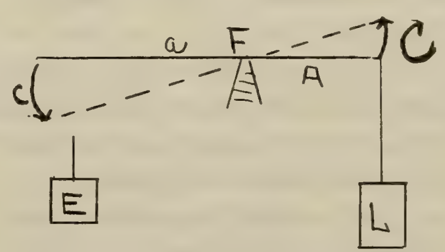

Fig. 4b

as much greater than the speed of the other body A (L) in rising as the heaviness of the latter exceeds that of the former."[3c] All this discussion appears obvious to anyone trained in modern physics. It was, however, sometimes a non sequitur in the Florentine culture. Giovanni Batista Benedetti (1530–1590), for example, wrote, "The laws of the lever do not depend in any way on the rapidity or on the extent of the motion."[13a] Accordingly, he rejected both Aristotle's statics and Jordanus' solution for the inclined plane.

From the proportion (3) we obtain

$$Ec = LC. \qquad (3a)$$

To claim that we are concerned here with a basic modern principle like that of work (for a ideal machine) seems to me improbable. The Greeks as well as their Renaissance followers generally thought analogically in proportions—not physically in products.

Let us return to our querry about the theoretical importance of the lever. If Archimedes and Galileo had been able to deduce a priori any machine-law from symmetry alone, they could then have used this law generally to derive the specific laws of all other machines. Galileo, himself, proceeds to apply the law of the lever to the steelyard, to the windlass and the capstan, to the pulley, the movable pulley, the block and tackle, and to the inclined plane. To prove the law of the lever, therefore, was fundamentally significant. Much ingenuity was expended by Galileo, as well as by many others in succeeding centuries, in attempts to derive the rule for any given machine from that of some other machine which was regarded as basic. The game was even varied as to whether an inverse derivation might not be regarded as equally fundamental. As Mach reminds us, "One well-considered and tested observation is as good as another."[10b] No mathematical proof, no matter how rigorous, can ever be identical with or even equivalent to physical experience itself. If we can identify a principle latent in any single fact, we can then proceed to recognize it in others.

Let us now consider the inclined plane (or wedge, or screw). The Greeks had little interest in such a plane, possibly because it was apparently too puzzling. Pappus' (ca. 300) attempt at a proof, the only one known, was incorrect owing to his belief that both a "static" force and a "kinetic" force would be necessary for such a body to be in equilibrium. Galileo corrected this particular error by noting that the approach for a body is the same whether it is moving with constant speed or is at rest. Jordanus[6b], or at least his "school"[13d], is customarily credited with the first derivation of the specific law of the inclined plane, namely,

$$\frac{E}{L} = \frac{h}{l}, \qquad (4)$$

where h is the height of the inclined plane and l its length—on the basis of what we have called "instinctive" machine experience. Nevertheless, we usually credit Simon Stevin (1548–1620) with the modern understanding of the inclined plane because of his ingenious discussion of it. He considers an endless chain placed about the plane (Fig. 5).

Instinctively we feel that there will be equilibrium inasmuch as any motion at all would imply perpetual motion, which we have never experienced—another instance of the Principle of No Sufficient Reason. Disregarding the symmetrical, lower part of the chain, we can look upon the upper left weight of the chain (say, the effort E) as balanced by the upper right weight (say, the load L). Since the chain is uniformly distributed, the weights are given by

$$\frac{E}{L} = \frac{h}{l}. \qquad (4)$$

In his "Hypomnemata Mathematica" (1608) Stevin states, "The distance travelled by the force acting is to the distance travelled by the resistance."[13b]

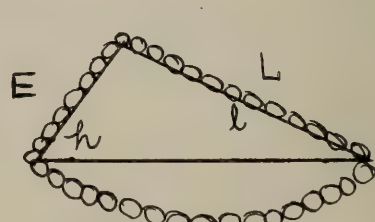

Fig. 5

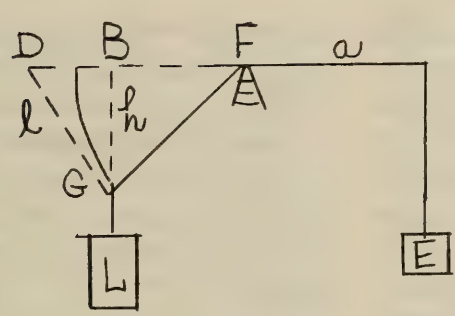

Fig. 6a

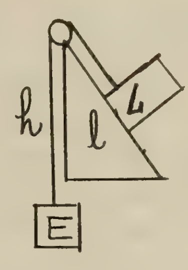

Fig. 6b

Turning to Galileo's books, "On Motion," "On Mechanics," and "Two New Sciences," we find him using the law of the lever (actually a bent lever) to prove the rule for the inclined plane. The following derivation is a slight modification of the one given early by Galileo.[13f]

In the diagram (Fig. 6a) the bent lever with load L and arm $\overline{BF}$, with effort E and arm a has its fulcrum at F; the tangent to the circle with radius $\overline{FG}$ = a may be regarded as the equivalent inclined plane $\overline{DG}$ with length l and vertical height h. Now the law of machines states

$$\frac{E}{L} = \frac{\overline{BF}}{a}. \tag{5}$$

But the right triangle DBG is similar to the right triangle GBF; hence for corresponding sides we have

$$\frac{h}{l} = \frac{\overline{BF}}{a}.$$

Upon substituting for $\overline{BF}/a$ in equation (5) we obtain

$$\frac{E}{L} = \frac{h}{l}. \tag{4a}$$

This expression agrees with equation (4) if the side h of Fig. 5 is made vertical, as is customarily the case (Fig. 6b), where the balancing effort E is provided by a weight suspended over a pulley.

In the discussion following the proof in his notes "On Mechanics", Galileo makes a highly significant comment. He points out that the travel of the load L (cf. Fig. 6b) is effective through the vertical height h while that of the effort E is along the length l of the plane. So he concludes, "One must not ignore the consideration which from the beginning has been said to hold for all mechanical instruments, that is, that whatever is gained in force by their means is lost in time and speed."[3d] We find the same idea expressed later in the "Two New Sciences."[1d] Mach, I believe, has rightly sized up the situation when he says, "Galileo's conception of the inclined plane strikes us as much less ingenious than that of Stevinus, but we recognize it as more natural and more profound."[10c] In other words, Galileo seems to delve more deeply into the subject. I am impressed, too, with the experimentalist's fingerprints; in his notes, "On Motion", he cautions that a physically real inclined plane must be "very carefully smoothed and perfectly hard."[3c]

A controversial question about Galileo's statics revolves about crediting him (and/or his many so-called precursors) with the so-called principle of virtual velocities (or displacements, or work). Before discussing who deserves credit for what, we might better specify just what we mean by this principle today. What is strictly the principle of virtual velocities? Let us consider the static equilibrium of a group of material particles q_i with generalized forces Q_i on each. Suppose that each particle is given an arbitrary, infinitesimal displacement δ_{qi} at the same time t. The principle of virtual work states that

$$Q_i \cdot \delta_{qi} = 0.$$

(It is usually convenient to restrict the displacements to those compatible with any given constraints.) This is the most general analytical statement of its kind; it is both the necessary and sufficient condition for equilibrium.

From a dynamic point of view, if the kinetic reactions (–mass × acceleration) are regarded as so-called effective forces, then the principle (1743) of Jean le Rond d'Alembert (1717–1783) states that equilibrium exists among the actual forces and these effective forces. By virtue of such equilibrium, we can at once apply the above principle of virtual work. In this way, dynamics can be reduced to statics, as was done by Joseph-Louis Comte de Lagrange (1736–1813) one hundred and one years after Isaac Newton (1642–1727) had first reduced statics to a special case of dynamics.

Historically, Jean Bernoulli (1667–1748) first enunciated broadly this principle for infinitesimal displacements, but without proof, in a letter to Pierre Varignon (1654–1722) on 26 June 1717. He was the first to recognize both the generality and utility of the principle for equilibrium problems. Subsequently (1788), Lagrange traced its historical development. Believing it necessary to base any "proof" of it upon some kind of mechanical experience, he himself took the case of a pulley system as easy to grasp, and attempted to derive the principle for it.[10f] In this way, he actually succeeded in giving mathematical expression to the experiential foundation of statics.

What are the possible germinal sources of this principle? What I have designated machine experience is certainly one, namely, certain common knowledge about gain in load at the cost of speed—something not just hidden in scholars' books, but familiar to everyday workmen. So we find, "In case of equilibrium (bodies at rest) the momenta, the velocities, or the tendency to motion, traversed by them in equal times, must be in the inverse ratio to the weights."[1d] In a footnote Crew observes, that this is "a near approach to the principle of virtual velocities."[1d] Toward the end of the "Two New Sciences", Sagredo remarks incidentally, "The velocity of a moving body, even its force is small, can overcome a very great resistance by a slowly moving body, whenever the velocity of the moving body bears to that of the resisting body a greater ratio than the resistance of the resisting body to the force of the moving body."[1a] The phrase "greater ratio than" signifies the observed direction of variation. Only for an ideal machine could there be equality. In this instance, ignoring the essential difference between products and ratios one might presumably see here the principle of work (strictly power in this instance), namely,

$$Ev = LV,$$

where v is the speed of the effort and V that of the load.

Some people would likewise read into the following statement of Aristotle something akin to this principle: "If, then, A the movent have moved B a distance Γ in a time Δ, then in the same time the force A will move $\frac{1}{2}$ B twice the distance Γ, and in $\frac{1}{2}$ Δ it will move $\frac{1}{2}$ B the whole distance Γ; for thus the rules of proportion will be observed." Certainly to see in this statement our modern concepts of velocity and of work is an anachronism, to say the least. We have here a typical instance of the use of proportions. Now proportions are a good mathematical device to be employed physically only when there is some experiential justification of the analogue. Even Aristotle cautions (wrongly) later, "But if E move Z a distance Γ in a time Δ, it does not necessarily follow that E, can move twice Z half the distance Γ in the same time."[14a] Aristotle's meaning, unfortunately, is not quite clear. Any operational criterion, indeed, is always difficult with Aristotle's ideas, because of his failure to solve actual problems. He was more adept in discerning questions than in obtaining their answers.

As noted above, the mere multiplication of force or weight by distance is not as simple a concept as it may nowadays appear to us. Torque and work, indeed, are quite distinct physical concepts involving directional differences. The recognition of the significance of products was d'Alembert's resolution of the famous 17th century controversy [10g] between the Cartesians and Leibnizians as to the efficacy of force. If you multiply force by time, then momentum is useful; whereas, if you multiply force by distance then vis viva is significant. The use of the latter product, however, had to wait until the 19th century

before it was even given a name by Gustav-Gaspard de Coriolis (1792–1843) and before it was used extensively by Jean Victor Poncelet, both of whom gave a geometrical touch to Lagrange's analytical approach. The discussion, indeed, continues even to this day. Is the concept of force fundamental or that of energy? From the idea of force one can derive that of work in the Galileo—Newton tradition which led to the school of Poinsot (who stressed the application of mechanics to machines). From the idea of energy, on the other hand, one can define force as the space-derivative of work—in the Galileo-Huygens tradition which led to the school of Poncelet (popular nowadays because of the technological importance of energy). Mach wisely cautions that "it was only gradually and with great difficulty that the concept of 'work' attained its present position of importance."[10d]

Looking back at Galileo's own contributions to the principle of virtual work, we are genuinely puzzled. Yet, without doubt Galileo recognized several important factors in the particularly simple problems with which he dealt.

First of all, Galileo emphasized the importance of direction. In a supplemental remark to his inclined-plane proof, he considers a component perpendicular to the horizontal surface. Later he remarks, "It is very important to consider along what line the motions are made."[3f] Galileo recognizes also the quality of some kind of "input" of a machine and its corresponding "output". Salviati says for him, "Do you not think that inclination, for example, of grave bodies to move downwards is equal to the resistance of the same to the motion of projection upwards."[15a] In many instances when Galileo deals with pendulums (and inclined planes) and free fall, where gains are considered ideally, he underlines this point of view. Later (1644) Evangelista Torricelli (1608–1647) gave a more precise statement about the lowering of the center of gravity of a system. Here again, there is greater instinctive appeal, but not more physical understanding. Christiaan Huygens (1629–1695) further generalized this statement of Torricelli, as well as Galileo's earlier one involving the relationship of height and velocity, in his so-called principle of conservation of vis viva (1673)—what we nowadays call the principle of conservation of mechanical energy.

In conclusion, Galileo, it seems to me, did use, and use properly, significant factors involved in the principle of work, as applied to machines, to pendulums and also to free fall. If one is generous, one can claim that he used the principle of virtual work in a "germinal form." Nevertheless, all such principles have to be ultimately evaluated in overall terms of aesthetic beauty and simplicity, of economy and usefulness, of understandability and familiarity, et al. It is always difficult to assign credit—particularly to nebulous germinal sources. Due credit, however, must be given to the specific applications by Galileo and Torricelli, by Descartes and Huygens. It has become fashionable nowadays in certain historical circles to give credit also to Leonardo, Jordanus, and even Aristotle. In this connection the late Professor Eric T. Bell concludes, "An extremely liberal interpretation of the ancient and medieval mechanical speculations has enabled some scholars to detect elusive hints of virtual velocities all the way back to the Greek philosophers."[16a] As a physicist, I prefer Lagrange's more conservative criterion, namely, the formulation of the principle in all its generality—by J. Bernoulli. Above all, I would limit credit to what is known to have been actually done—not to what is speculated as to what might have been done.

Let us now turn to the second aspect of Galileo's statics, namely, hydrostatics. Although, historically, the laws of statics were derived from observations of solid bodies, there is no a priori reason why they could not have been directly discovered from experiences with fluids. Fluids, indeed, offer an additional advantage in that they introduce us to the concept of a physical continuum, which turns out to be more fruitful for ordinary mathematical applications. I should like to stress some points with respect to Galileo's interest in fluids.

First of all, let us consider buoyant forces. Galileo has evidently a complete understanding of the work of Archimedes, the founder also of hydrostatics. The famous principle of

Archimedes is embodied in Proposition 6 (for lighter bodies) and 7 (for heavier bodies) in his first paper "On Floating Bodies".[8b] With publication of his works (and translations) in the 16th century there was renewed interest in such phenomena. Galileo[12b] seems to have been particularly impressed with the buoyancy of a body floating in a relatively small amount of fluid which could apparently raise or sustain a body a hundred times heavier—contrary to Aristotelian expectations. At the end of his book he notes enthusiastically that a ship which can displace six fathoms of water can float in water six fathoms and one half inch deep. I myself am fascinated by his remark that "water has no gravity in water"[12c]—similar to Stevin's endless chain.

Of special interest is Galileo's experimental testing of floating bodies. A question had arisen in Florence as to the properties of cold bodies.[12d] Take ice, for instance; being cold it should be denser than water; being denser, it should sink—but ice floats. Aristotelians claimed that the apparent buoyancy was owing solely to the shape of the ice. In his "Discourse on Bodies in Water" published in 1612, Galileo reports a thorough experimental investigation of this matter. He cites Aristotle, himself, against the Aristotelians, "The shape of bodies will not account for their moving upward or downward in general, though it will account for their moving faster or slower.[14b] He starts with the observations that a flat piece of ice rises to the top and floats[12e] even if put originally on the bottom, and that ice in the form of a sphere also floats. He mentions how wood being soaked with water or plugged with lead sinks, and how "air combined with glass", as in the case of an empty tumbler, floats. Most ingenious, however, is his use of wax figures[12f] (to prevent water logging) about the size of an orange. He inserts metal filings in them so that they become sensitive to a single grain as to whether particular shapes float or sink. (He mentions that he has never been able to get a model to remain stationary within the water.) In the "Two New Sciences"[1f] Sagredo, too, recalls experiments with wax balls embedded with grains of sand. In this case he cites also experiments at the interface of salt water and ordinary water, and the use of a ball to test the purity of water. For example, by adding two grains of salt to six pounds of water one can make such a ball rise; by adding 4 drops of warmer or colder water one can have a ball fall or rise, respectively. In a letter written to the Grand Duke of Tuscany prior to the publication of his book he rightfully boasts, "I have perhaps better investigated the causes of the matters which constitute the subject of the present contest than did Aristotle."[12g]

The observational evidence, however, that perplexed him most was the problem stressed by his opponents, namely, the floating of an ebony chip. Galileo recognizes immediately that the critical state of the ebony chip[12h] is owing to the failure of the liquid to wet it. His diagrams, indeed, show the proper angle of contact for non-wetting. He tries many ingenious arguments to explain the phenomenon solely in terms of the cavity of dimple that is produced by a floating body. All this effort, however, was to no avail in view of his ignorance of surface tension, which combines with the buoyant effort.[18] Surface tension, to be sure, was not understood until the work of Pierre Simon de Laplace (1749–1827) a century and a half later. In the "Two New Sciences" Sagredo admits his own perplexity, "If there be no tenacity or coherence between the particles of water how is it possible for those large drops of water to stand out in relief upon cabbage leaves without scattering or spreading out?" Salviati replies sincerely, "Let me confess I do not understand how these large globules of water stand out and hold themselves up."[1g] Regardless of the failure of his heuristic explanation, Galileo certainly shows great skill as an experimenter in trying to ferret out this secret of nature.

Although our present discussion is not concerned particularly with motion,[3] I must call your attention to those germane experiments[1f] of Galileo with respect to liquids because they are highly significant. He insists repeatedly that the start of motion[12i] downward or upward in a fluid is essentially the result of the buoyant force which, in turn, is dependent upon the specific gravity of the body relative to that of the medium—all of which started him on his critical discussion of the free fall

of bodies. For example, two falling bodies with a fixed difference in specific gravity will separate further as time goes on. As for up-and-down movement he rejects early the idea of any levity in addition to universal gravity. In line with Plato, he concludes that gravity alone is basically sufficient for understanding the movement of bodies up and down. He cites the case of a boat traveling upstream. How far it will go will depend upon the speed of the boat relative to that of the stream. He recognizes, of course, that the resistance of a medium is a major factor in determining a body's limiting speed. It is owing to such considerations that he conceives the possibility of a vacuum.

Galileo is interested also in the equilibrium of a liquid in connecting vessels,[12j] the so-called hydrostatic paradox, i.e., the apparent balancing of a large amount of liquid in the wide arm of a U-tube by the small amount in the narrow airm. Here he invokes again machine experience (paying due credit to Aristotle); he formulates it as the third of three axioms (and five definitions) given at the beginning of his discourse, viz., ''Weights absolutely unequal, do alternately counterpoise and become of equal moments, as oft as their gravities, with contrary proportion, answer to the velocity of motions.''[12k] He uses this axiom here only in connection with this specific problem. I cannot wholly agree with the sweeping remark that ''essentially his hydrostatics was based on the principle of virtual velocities, which was directly inspired by Aristotle's mechanics.''[13c] Assuming that the liquid in a connecting vessel is in equilibrium, he notes that either vertical displacement for any disturbance is inversely proportional to its corresponding cross-sectional area, and hence to the weight of the whole liquid on that particular side. As Mach has indicated,[10e] this is not strictly true, inasmuch as any liquid so displaced would necessarily have its center of gravity raised—contrary to the natural motions of a free body.

Later Blaise Pascal[19a] (1623–1662) analysed correctly the case of a confined weightless fluid. If w is the weight (E) applied to the narrow arm (Fig. 7) and W the load (L) on the wide arm, h and H the corresponding displacements, s and S the corresponding cross-sectional areas, then from machine experience we have

$$\frac{w}{W} = \frac{H}{h}.$$

From the geometry of the apparatus for a displaced volume V

$$V = sh = SH.$$

Hence

$$\frac{w}{W} = \frac{s}{S},$$

or

$$\frac{w}{s} = \frac{W}{S}.$$

This constant quantity is called the pressure (first conceived by Pascal). He had to assume that the fluid is incompressible and that the pressure in this case is transmitted instantaneously. His conclusion, we now know, applies also to a compressible fluid so that the argument has to be changed accordingly. The hydraulic press, a hydrostatic machine that specifically utilizes Pascal's principle, probably evolved out of Galileo's initial discussion.

One final remark with reference to Galileo's hydrostatics! As Stillman Drake [12l] has emphasized, this is Galileo's first publication on experimental physics. The experiments, though simple, are interesting and well-designed. They are used to explain phenomena on the basis of known physical principles. The material is not given in Archimedes' deductive fashion; instead, a number of specific cases are cited. Thus, Galileo boasts, ''I, with a different method, and by other means, will endeavor to demonstrate the same, reducing the causes of such effects to more intrinsical

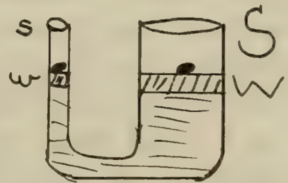

Fig. 7

and immediate principles.''[12m] Here we have the essence of modern theoretical physics. In Galileo's time it had become impossible to deduce natural phenomena from the first principles of philosophy. Hence Galileo, following Archimedes, sought intermediate physical principles which could be used to describe and predict the observed phenomena, as indicated below:

First Principles of Philosophy
|
Intermediate Principles of Physics
↓
Observed Phenomena

The gap thus created between speculative philosophical principles and pragmatic physical principles has unfortunately persisted to this very day. In this respect, perhaps one should keep in mind the sound advice of Leonardo da Vinci, [20] ''Remember when discussing about water to use first experience and then reason.'' Certainly, Galileo employs both experience (occasionally experiments) and reason in a remarkably effective manner to understand phenomena themselves. I agree with Stillman Drake that Galileo is revealed here as ''the first truly modern physicist.''[12n] It is so easy to concentrate upon Galileo's more glamorous theoretical deductions of the two new sciences that we may be inclined to underestimate his significant experimental explorations.

These hydrostatic investigations were readily understood in the 17th century. Galileo became immediately popular—and, therefore, naturally unpopular. His book turned out to be the spark that ignited the spontaneously combustible resentment of various groups antagonistic to such a clever and articulate personage.

Let us turn now to that other ''new science'', the strength of materials. It is strange that so little interest has been shown by professional historians of science in this particularly original work of Galileo. Is it possibly too practical? Nevertheless, his scientific approach here has had great historical significance. It opened up a whole new field of beautiful and useful ideas, the first publication in this area. The special problems studied led to the modern theory of elasticity with the establishment (1821) of Louis M. H. Navier's equations of motion and conditions of equilibrium. As Abraham Wolfe[21] claims for this new science, ''We may say the foundations of engineering theory were first laid,'' i.e., the beginning of engineering science. In its theoretical ordering of phenomena according to physical principles Galileo established a logical structure. Despite some wrong theoretical assumptions he gave a direction to subsequent investigations of the strength of materials, including rupture.[22]

Certainly Galileo is at his best in his casual approach to this problem. He starts at an everyday place—an arsenal. He tells of the reply of an old workman to Salviati's query as to ''the reason why they employed stocks, scaffolding and bracing of larger dimensions for launching a big vessel than they do for a small one.'' Just how much of Galileo's theoretical analysis of this question may have actually been *experimentally* based? Because of his excellent artistic presentations, there is always some reasonable doubt—though none whatever as to its *experiential* foundation. We shall consider some specific problems he discussed generally in the ''Two New Sciences.''

Galileo begins with the idea of the ultimate tensile strength (Fig. 8) that a suspended material can sustain. He finds that simple tension is proportional to the cross-sectional area, but independent of the length—a somewhat unexpected result. For example, a wire of copper weighing one ounce and one cubic long, he notes, was able to support 50 pounds prior to its rupture, i.e., about 6,450 pounds per square inch (on the basis of modern data, more likely 49,000 pounds per square inch).

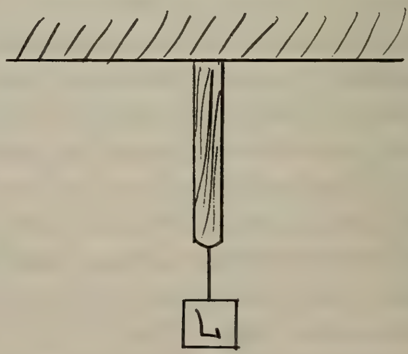

Fig. 8

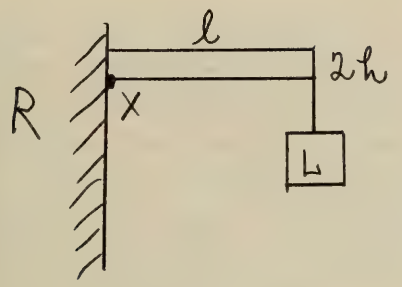

Fig. 9

In this connection Galileo finds himself wondering about the ultimate strength of a vacuum.[1j] Water experiences only a limited resistance to a vacuum, as had been found practically in the non-operation of a lift-type pump, i.e., a column of water presumably "breaks" if it is more than 18 cubits high. This finite force of a vacuum, he suggests, should be separated out as a sort of zero correction in determining the strength of materials.

We come now to what is commonly called "Galileo's problem."[1k] He considers a bar of length l and thickness 2h used as a cantilever (Fig. 9) first with only a load L, then with solely its own weight, and finally with both. He assumes that fracture occurs at the juncture X owing to a uniform resistance R of the tensile strength of the material fibers at that end of the beam. On the basis of the lever principle, using X as the fulcrum he notes that $R/L = l/h$. A steel or glass rod, for example, which sustained 1,000 lb longitudinally, broke under only 50 lb when attached horizontally.

Towards the end of the century, Edmé Mariotte (ca. 1620–1684) improved Galileo's solution. Having to design water pipes for Versailles, he became interested in the strength of materials. He found that empirical values were all less than those given theoretically by Galileo. Accordingly, he investigated critically the assumptions. The fibers, he decided, are actually deformed, even in the case of brittle materials. In 1680, using Hooke's law which he established independently, initially for tension only, but then for tension and compression, he obtained theoretical values more compatible with those observed. (Hooke's law, unfortunately for this purpose, does not hold entirely up to the point of rupture.) Galileo's naive assumption, nevertheless, did not vitiate his subsequent deductions inasmuch as they involve relative strengths of materials and not absolute values. At any rate, the direction of future investigation was thereby determined early in the 17th century.

Galileo discusses the "ruler problem",[1l] viz., whether a ruler embedded horizontally in a wall will have greater strength if it is flat or if it is on edge. He concludes rightly that there is greater resistance to fracture when the ruler is on edge. In this connection he investigates the resistance due to other factors such as the length of a beam, its diameter, et al.

A most interesting and important investigation involves symmetrical beams.[1m] Under what conditions do they fracture because of weight alone? The bending moment is proportional to the 4th power of a characteristic linear dimension, whereas the resisting moment is proportional only to the third power. Hence larger beams will necessarily become weaker by virtue of their own weight—an unexpected fact. Sagredo expresses his intellectual chagrin, "Since mechanics has its foundation in [mathematical] geometry, where mere size cuts no figure, I do not see that the properties of circles, triangles, cylinders, cones and other solid figures will change with their size."[1h] Nevertheless, nature here insists upon regarding material properties themselves, not just abstract (geometrical) proportionalities, in its laws of scaling. Salviati concludes, "You can plainly see the impossibility of increasing the size of structures to vast dimensions either in art or in nature."[1n] He had previously noted, "Nature cannot produce a horse as large as twenty ordinary horses or a giant ten times taller than an ordinary man."[1a]

Galileo takes up also the case of a doubly supported beam. Here again he finds his inspiration in a practical problem. A large marble column resting on two supports had been given a third support at the center to insure

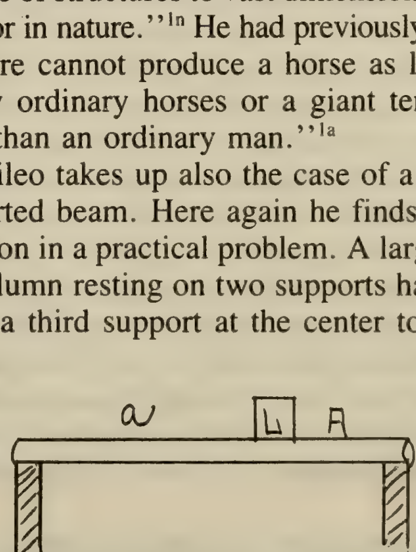

Fig. 10

its safety. After some months a crack developed precisely at this position. In solving this problem he considers a load L (Fig. 10) at a distance a from one support and at a distance A from the other one. He deduces that the bending moment is greatest just beneath it. Moreover, it is proportional to the product aA, which evidently becomes a maximum for the distance a equal to A. Thus the maximum bending moment for a given load will occur at the center of a beam—as in the case of breaking a stick across one's knee. The amount of material, therefore, can be reduced at the ends without sacrificing any resistance to bending.

Of particular theoretical interest is the investigation of solids of equal resistance.[1q] Specifically, what is the generating curve of a solid such that the resistance at each cross-section will be exactly equal to the tendency to rupture there? Galileo, finds that the generating for a rectangular cross-section curve is a parabola (Fig. 11). One can thus eliminate about one-third of the material (outside it), and yet still have a beam of the same strength. A memorable controversy[22] ensued! It is surprising that the close relation of this problem to the mathematical theory of elasticity did not produce more development in that direction. Rather it was the flexure of a horizontal beam that was almost entirely significant in this regard.

Finally, Galileo considers the relative strengths of two beams, having the same length and the same weight, one of which is solid and the other hollow.[1r] Now their absolute strengths are the same, but their resisting moments are proportional to their respective diameters. Salviati cites experiential corroboration of the theoretical conclusion, "It is found that a hollow lance or a tube of wood or metal is much stronger than would be a solid one of the same length and weight."[1r] He illustrates in the cases of the bones of birds, the stem of a wheat straw, et al. There has, of course, been much subsequent improvement along this line as mathematical and experimental techniques have been further developed.

As a physicist, I am always impressed by Galileo's amazing insights, his sense of phys-

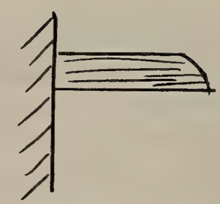

Fig. 11

ical significance, his combination of experiential evidence and theoretical reasoning. The whole development of the strength of materials, I believe, is an excellent illustration of Galileo as a working physicist.

In conclusion, I should like to comment more generally on the relative roles of practical experience, of mathematical reasoning, and of phenomenological understanding—particularly with reference to the scientific outlook of Galileo.

Galileo's whole practical interest and experience is exhibited in his beginning statement of the "Two New Sciences," his most important scientific book. The Florentine Salviati graciously remarks, "The constant activity which you Venetians display in your famous arsenal suggests to the studious mind a large field of investigation, especially that part of the work which involves mechanics; for in this department all types of instruments and machines are constantly being constructed by many artisans amongst whom there must be some who, partly by inherited experience and partly be their own observations, have become highly expert and clever in explanation."[1s] In a sense this is appropriately Galileo's valediction.

As early as 1597, Venice had given Galileo a patent for the erection of a water-raising machine. We are all familiar with him in 1610 as a *manu*facturer of compasses and telescopes. In 1630, in his capacity as superintendent of Tuscany Waters, he wrote a report on the river Bisenzio. It is said that he produced "the first well-founded set of range tables", vitiated, to be sure by the neglect of air resistance, which had yet to be appreciated—by reference to these very tables. Even in 1641 we find the blind Galileo deeply concerned about his idea for combining the motion of a pendulum with the escapement of a

clock (pinwheel type). This idea had to wait another one hundred years for its utilization.

August E. H. Love rightly concludes his introduction to the "Mathematical Theory of Elasticity," "Most advances in natural philosophy have been made by men who have had a first-hand acquaintance with practical needs and experimental methods."[23] Certainly this was true of Galileo!

Carl Friedrich Gauss (1777–1855) boasted of mathematics, "the queen of the sciences." But like other monarchs mathematics is no longer queen. Many, indeed, would argue (correctly) that mathematics is not even a science. There are some few physicists, to be sure, who still regard science as a materialization of mathematics, but most physicists today regard mathematics as a scientific tool. Mathematical physics, strictly speaking, is essentially physics—in its mathematical aspects. It is interesting that Bell himself first praised "The Queen of the Sciences" (1931), and then later recognized "The Handmaiden of the Sciences" (1937), but finally paid homage to "Mathematics, Queen and Handmaiden of the Sciences" (1951). As far as nature is concerned, mathematics discloses only patterns latent in the assumptions. In line with the whole Greek philosophical approach (exaggerated in Platonism), Archimedes and Galileo both hoped initially to demonstrate from certain first principles the validity of their findings; but insofar as there is any natural validation at all it is inherent solely in the experiential principles chosen as fundamental. I do not believe "we can demonstrate by geometry that the large machine is not proportionally stronger than the small."[1t] (Galileo's geometry was physical geometry, including physical factors.) Yet I do recognize the scientific value of mathematics within the proper limits of our understanding nature. Salviati rightly observes, "I wish to convince you by demonstrative reasoning"[1u]—provided, of course, he starts from known and accepted experiential facts, not merely from a priori ideas.

Galileo's unique contribution to the continuous development of man's understanding of nature, I believe, is his recognition that phenomena themselves present an additional necessary criterion for determining "whatsoever things are true." He himself (I am certain) did not wholly appreciate the relation of the content of the book of nature to the language in which it is written. Nevertheless, he continually discloses an experiential approach—often a definitely experimental method, i.e., asking specific questions of nature—including deductions from assumed physical principles, not just inductive observations of nature, and certainly not mere deductions from a priori first principles of philosophy.

As one reads and rereads Galileo's truly living works, one is always impressed with his persistent intellectual quest to understand nature. When Sagredo confesses, "I, myself, being curious by nature,"[1s] we detect Galileo's own handwriting, his intellectual signature. With respect to his life-long interest in pendulums he slyly admits that it is "a subject which may appear to many exceedingly arid, especially to those philosophers who are continually occupied with the more profound questions of nature."[1v] The Venetian Sagredo, too, is admittedly impressed, "You give me frequent occasion to admire the wealth and profusion of nature when, from such common and even trivial phenomena, you derive facts which are not only striking and new but which are often far removed from what we would have imagined." What a true evaluation of Galileo as a physicist—particularly in his investigations of statics.

May I close this chapter of the Quatercentenary Commemoration with a poet's musings about this lover of poetry and nature? Celeste, Galileo's faithful daughter, muses,

"It may be
That he was wrong in these things, and must pay
A dreadful penalty. But you must explore
His mind's great ranges, plains and lonely peaks
Before you *know* him, as *I* know him now.
How could he talk to children, but in words
That children understand? Have not some said
That God Himself has made His glory dark
For men to bear it."[24]

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How Commercial Buildings Use Energy

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ABSTRACT

Energy use in buildings had not become the subject of a comprehensive scientific study until the mid-1970's. Even now there is insufficient research being undertaken, due primarily to the lack of cohesiveness of the building industry. Research done to date indicates that commercial buildings act in a very different manner than residences; lighting and cooling tend to be the primary energy problems. A commercial building's form and orientation, and lighting, envelope and mechanical systems can be designed to use less energy but this potential is limited by a lack of understanding of fundamental issues. Thus buildings tend not to use the energy sources present in their surrounding environment in any significant way, yet this environmental energy source is quite substantial.

1. Introduction

Buildings use one-third of the total energy consumed in the U.S. (The remaining energy use is split roughly equally between transportation and industrial production.)

Approximately 60% of the energy consumed by buildings in the U.S. is consumed by residential buildings, and 40% by commercial. A large part of the residential stock currently exists in cold climates so the majority of past research on building energy consumption has focused on reducing the need for heat in cold-climate houses. This tends to be the ''intuitive definition'' of the boundaries of building energy research by the public or policy-makers. There are two problems with such a definition of the research question:

a. The demographic trend in the U.S. is a population shift substantially to the south. Dr. James Brown of the MIT/Harvard Joint Center for Housing Studies predicts that over the next 10 years, 50% of the U.S. population growth will occur in just three States: Florida, Texas, and California.
b. Heating has very little to do with the energy problem of modern commercial buildings (as will be explained later).

We have come a long way in understanding how to reduce heating loads in houses, using passive solar or energy conservation (e.g. insulation) techniques. However, a substantial portion of the national research problem remains. We know very little about the convective heat transfer mechanisms that could be used to cool houses in hot climates, particularly hot-humid climates. Secondly there is much unknown about energy use in commercial buildings, and it is this latter subject that will comprise the remaining discussion in this paper. (1)

The reasons why commercial buildings use as much energy as they do, are not well understood. Relatively speaking, energy use in commercial buildings has received little research attention in the US due to a number of dichotomies of perspective. Of the total funds expended by a commercial building owner (or renter) over the life of a building, over 90% will be invested in the salaries of the occupants. The energy cost to provide environmental conditioning of the building's interior is thus a secondary priority despite the national energy importance of buildings. Secondly, the process of producing buildings is not one that is amenable to improvement in energy efficiency because:

a. The building ''production industry'' comprises a diverse, unstructured group that includes product and material manufacturers and suppliers, general contractors, construction trade workers, architects, mechanical, electrical, and civil engineers, homebuilders, home manufacturers, building code, zoning, and planning officials, realtors, real estate lenders, and real estate developers.
b. The decision-making process is generally diffused among the above groups; no one group has total responsibility.
c. The thermodynamics of building energy flow occurs in a regime of small temperature differences, a regime not well understood scientifically.
d. Buildings are the longest-lived ''products'' made in the US so the building industry tends to be extremely conservative. The typical anecdotal illustration of this fact is that twenty years elapsed between the invention of plywood and its common use. I was once told by representatives of fossil-fired heating equipment manufacturers that they have difficulty meeting energy efficiency standards because the basic design of such equipment has not changed in 50 years. (I fear that their perspective will be soon broadened by Japanese manufacturers.)
e. Building design is regulated by health and safety codes that vary substantially by local jurisdiction. ''National products'' are difficult to produce in a way that meets all U.S. codes.

Weighed against the above problems is the fact that improvements are sorely needed in buildings because:

1) Buildings are the longest-lived ''products'' made in the U.S. so energy-wasting buildings are with us for a long time.
2) Most people in the U.S. spend almost all their lives within buildings; a comfortable, pleasing environment is mandatory for their physical, emotional, and spiritual well-being.

Improvements in energy use in the building sector have occurred very slowly, more slowly than in other sectors as evidenced by the fact that the building sector's fraction of U.S. energy consumption has risen from 29.8% in 1960 to 36.1% in 1983. (2)

2. History

From the recorded history available to western civilization it appears that buildings until quite recently were typically heated by small fires in individual rooms when they were heated at all. Most lighting was provided by natural light and cooling by natural ventilation. Occasionally communities would actually plan to take advantage of the sun's heat and light. When the new city of Olynthus was built in Greece, it was built on the south side of a mountain with streets laid out such that all buildings had good access to sunlight; this occurred around 450 BC but rarely since then. The Romans appear to have built passive solar bathhouses using glass or mica glazing; Seneca mentions this in a letter in 65 A.D. and again this has occurred rarely since then. (3) (There are Roman records of lawsuits concerning buildings blocking other buildings' access to sunlight dating from the second century A.D.; lawsuits have unfortunately not occurred rarely since then.)

In general buildings were heated by wood and then coal for hundreds of years. The London ''fog'' made famous by Arthur Conan Doyle was in fact smog from coal stoves. This

"fog" dissipated when these stoves were replaced by oil or gas heaters but this did not occur until fairly recently.

In 1784 James Watt heated his office with a central steam piping system. Forced ventilation systems and water-spray air purification began to appear, allowing buildings to increase in size somewhat. Building dimensions were still limited by the 15 feet or so, that daylight could penetrate from windows. The invention of incandescent lighting did little to alleviate this problem because 90% of the energy consumed by these lamps did not produce any light, just heat. There was no efficient way to remove this heat, the only available techniques being natural or fan-forced ventilation. So, occupied buildings remained small until well into the 20th century. (4)

The (more or less) simultaneous invention of flourescent lighting and practical electric-driven air conditioning allowed buildings to change dramatically in the late 1930's and early 1940's. Windows became unnecessary for lighting or ventilation and buildings could be built as cavernous as the capability of structural engineers allowed. As long as electricity was inexpensive an office worker could be miles away from a window and still have a thermal and lighting environment considered comfortable. Of course, senior corporate management didn't deem windowless offices comfortable for senior corporate management.

The Arab oil embargo caused some of the building community to wonder why it was necessary to purchase electricity to light and cool a building occupied during that part of a 24-hour period when there was a lot of daylight available. At the same time developers noted that companies were willing to pay higher rents for office space with daylight and good views, to satisfy an increasingly sophisticated workforce. (Thus the atrium has become a more common feature of commercial office space.) The embargo stimulated an interest in providing buildings in which natural light, heating, and cooling simultaneously offer amenity to occupants and reduced energy costs to the owners.

In summary, the building cooling and lighting equipment used today is conceptually only forty or fifty years old. As an established, integrated area of scientific and engineering investigation a major study of building energy use is only a little more than 10 years old.

3. Basic Concepts

Buildings, like humans, require energy for heating or cooling when there is an imbalance between the heat normally produced within the building and the heat lost or gained through its skin. Buildings require energy for lighting when there is insufficient penetration of daylight within. The internal generation of heat within buildings is considerable and comes from lights, people, and equipment. Every watt of electricity consumed in a building turns into a watt of heat and the recent explosion in the use of personal computers and reproduction equipment has caused this internal heat generation to rise dramatically. Heat is also gained within buildings by the penetration of sunlight through glazing. In all but the smallest human-occupied commercial buildings, with modern levels of insulation summer heat gain from conductivity through the opaque portions of the walls and roof is a minor issue, contrary to popular intuition.

Heat is lost from a building through conduction and convection through the building skin. Conductive losses in buildings depend, as in any thermodynamic system, upon the temperature difference between the interior & exterior, the surface area available for heat transfer, and the conductivity of the skin (generally limited by insulation mostly to preserve human comfort in the perimeter zones). Convective losses occur through cracks in the skin and are poorly understood but presumed to be somewhat a function of wind speed; little measured data exist upon which to base theoretical calculations.

The surface area of a cube increases as the square of its linear dimension but the volume increases as its linear dimension cubed. Thus, as the size of a building increases its volume increases faster than does its surface area. In larger commercial buildings far more internal heat is produced than can escape through the building skin during the time the building is

occupied. At night, only the skin loss must be compensated. The result of all this is that the daytime cooling loads in most commercial buildings, even in cold climates, are larger than the nighttime heating loads, again contrary to popular intuition.

If the "energy problem" in a building were to be defined in terms of the energy consumed by the building's lighting, cooling and heating systems respectively, the result would typically be that the lighting system consumption is the highest, with heating and cooling second and third, or third and second, depending on climate and internal loads. However, if heating is produced from natural gas and cooling from electricity, the order of priority in terms of annual *cost* to the building owner will almost always be lighting first, cooling second, and heating third. (Natural gas is about one-third the cost of electricity per BTU because electric power plants operate at a thermodynamic efficiency of approximately one-third.)

If the order of priority of the energy cost in a building is lighting, cooling, and heating, the typical energy conservation measures used in residences are substantially ineffective in commercial buildings, again contrary to popular intuition. (5)

4. Building Systems

To reduce the energy use in a commercial building, experienced building designers manipulate various aspects of the building during the design process. These aspects can be categorized as form and orientation, the lighting system, the envelope system, and the mechanical system.

A. Form and Orientation

Within the constraints of the site and building budget, a building can be made less "compact" if penetration of daylight and natural breezes is to be enhanced in the design. Daylight provides energy savings in two ways in buildings so long as the electric lights are turned off when sufficient daylight is present. First is the obvious savings in electricity for lighting. The second saving is not as obvious. All lighting systems consume more energy than is directly converted to light. Luminous efficacy can be defined as the light output of a source divided by the heat it adds to a space. Incandescent sources have efficacies ranging from 10 to 30 lumens/watt, and flourescent sources tend to operate at 65 or 70 lumens/watt. Daylight provides an "equivalent" efficacy of 100 lumens/watt. As long as the building is designed so that no more daylight is allowed to penetrate than is actually needed, daylight reduces the cooling load in a building.

The high mid-day summer sun does not penetrate into buildings nearly as easily as the low, morning or late afternoon summer sun. It is generally effective to orient a building so its long axis is east-west to reduce the east and west window areas and thus reduce cooling loads.

It would seem that for a given type of building with a given energy problem, there should be a preferred form and orientation to minimize its energy consumption, or perhaps two preferred configurations: one to allow maximum climate response (daylighting, ventilation) and one to allow maximum climate defense, depending on design philosophy. However a rigorous investigation of this basic issue has never been conducted.

B. Lighting Systems

As we have seen, lighting is usually the critical issue in commercial building energy costs. (Warehouses in northern climates are an obvious exception.) Lighting is also the most controversial issue due to a fundamental technical problem. There is a commonly accepted quantitative definition of human *thermal* comfort that includes ranges of temperature, humidity, and air movement, and varies depending on the level of physical activity in which a particular human is engaged. Surprisingly no such quantitative, accepted definition exists for human *lighting* (or visual) comfort. Definitions have been proposed but none has proved satisfactory, presumably be-

cause light has so much more profound and complex an effect on human psychological and physiological well-being.

In the past lighting systems have been designed using a metric of quantity (footcandles) with the assumption that more was always better unless resulting cooling loads became completely unreasonable. There may have been some justification for this since visual tasks in the past were more difficult: pencil lead on yellow paper and mimeographed copy are difficult to read. Black-and-white xeroxed copy or computer screens have high contrast and are much easier to read. As well, eye care and corrective lenses are much more available. It appears that beyond some threshold necessary to perform a particular task, a high quantity of light does not substantially contribute to increased visual accuracy. The direction from which the light originates relative to the occupant's eyes is much more important. That is, the distribution of the light sources appears to be a key issue, to avoid glare and veiling reflections.

Due to the lack of success of past attempts to quantify lighting quality, lighting design is today more art than science, conducted with heuristic rules when it is conducted at all. Most building designers have not been trained in lighting design and there is only a handful of schools that offer lighting design curricula, a fact that continues to astonish me. There exist a number of excellent lighting designers who can illuminate spaces in ways that create visual pleasure, sparkle, and even magic. They tend only to be hired for situations where lighting is critical to commerce (retail stores, hotel lobbies) or corporate image (corporate headquarters buildings). Most building lighting systems are "designed" by persons with little background or training in lighting design.

Given the above, it is clear that the creation of good lighting with good energy efficiency is a murky issue at best. One can improve lighting energy efficiency with more efficient equipment to reduce installed power, and more sophisticated controls to reduce unnecessary time of use. Energy, the product of power and time is thus reduced. More efficient luminaires (light fixtures) and their components, lamps and ballasts (high voltage transformers) are available. Electronic switching including occupancy sensors and daylight sensors are available to dim or turn off luminaires when appropriate. These techniques can greatly reduce lighting energy consumption without changing the quality of the visual environment. An alternative technique often used is to remove luminaires from a building. This method, prevalent in situations where the use of a lighting designer has never occurred to anyone, almost always has the effect of making a bad lighting situation worse.

A scientific basis for lighting design in general, and energy-efficient lighting design in particular, is sorely needed. Until this is developed, good lighting will be done by good designers on an empirical basis for a small group of buildings and the remainder of the population will continue to work with lighting that is at best, haphazard.

C. Envelope Systems

Of the four issues discussed in this section, building envelope systems have received the most research attention. Insulation and winter solar heat gain can reduce building heating loads and improve human comfort by increasing the radiant temperature of room surfaces. However, cooling loads are generally a more significant and more complex concern. Here, conductive heat gain tends to be a smaller issue because the interior-exterior temperature difference in the summer is small.

The largest contributors to the cooling load in the perimeter of a building are the solar heating through glazing and the lighting system. (People and equipment albeit large contributors to the cooling load are obviously not amenable to manipulation by building designers.) Lighting contributions to the cooling load can be reduced through the techniques discussed previously. Specifically sensors can be employed to dim perimeter luminaires when daylight is present. Daylight penetration into rooms can be enhanced with skylights, roof monitors (which were a primary source of light at the beginning of the industrial revolution) or "light shelves" that reflect light

from the perimeter glazing to the room ceiling.

Solar heat gain can be reduced in a number of ways. The most obvious is to reduce the window area of the building, to that area needed for view by the occupants. This was common in areas with intense sunshine and hot climate but fell from favor when architectural style became international in focus. Recently designers have begun to feel that architectural style might acceptably vary according to regional preferences and climate as it once did, and there is an emergence of vernacular architecture.

The question of suitability of architectural style is an emotional issue beyond the scope of this discussion. It is reasonable, however, that building designers may not want to be limited in the use of glass; there are alternatives available. Glazing can be shaded by external projections from the building much as awnings are used in residences. Or, glass with a lower shading coefficient can be used. Shading coefficient is roughly speaking, the amount of solar *heat* gain the glass will transmit relative to that transmitted by 1/8 inch thick, clear double strength glass. To really reduce heat gain very low shading coefficients can be used and these are commonly called reflective glazings. These glazings have two negative aspects. First, low shading coefficient glass tends to have a low visible light transmittance so the outdoors appears dark to a person inside the building. (The shading coefficient of glass is not necessarily coupled to its visible transmittance but often this is the case.) Particularly on a cloudy day it can appear that a thunderstorm is always imminent. Second, such glass has the external appearance of a mirror which is not to everyone's liking. In fact, it's overuse has caused it to be outlawed in San Francisco.

The building designer can use glazings with moderate shading coefficients and visible transmittances, and manipulate daylighting and lighting strategies, glass area or external shading devices to minimize cooling loads while not increasing heating requirements. This is currently done on a case by case basis since systematic rules of thumb are just beginning to emerge for a few building types in a few climates. Only a few designers are proficient in energy design of building envelopes.

Another research issue is the extent to which modern building envelopes allow unintentional air leakage, commonly termed infiltration. This has been studied to some extent in cold-climate residences but seldom in commercial buildings. Yet infiltration is potentially a major contributor to energy consumption in a building perimeter.

D. Mechanical Systems

Commercial building mechanical systems, commonly referred to as Heating, Ventilating, and Air-Conditioning (HVAC) systems, are substantially more complex than residential systems because it is common for different zones of a commercial building to respectively have heating and cooling loads at the same time. For example, for an office building on a winter day in a cold climate the building core will require cooling, as it always does since the internally generated heat has no natural escape path. The north perimeter zone will require heat and the south perimeter zone may or may not need heat depending upon the penetration of sunlight through the glazing. The east perimeter zone may require cooling in the morning due to low-angle sunlight penetration but heating in the afternoon; the west perimeter zone will act in a similar but opposite manner.

To respond to these varying loads mechanical engineers will devise a HVAC system that sequentially: moves air through a room, transferring heat to water in a pipe loop, that transfers heat to a refrigerant loop with compressors and evaporators, to move the heat outdoors. The water loop is optional but usually necessary in large buildings because water has so much higher a specific heat capacity than air. Fan power requirements and the sheer physical size of ducts prevent the use of air as the major heat transfer medium; air is only used as the medium in the initial stage of the heat transfer process in large buildings.

HVAC equipment efficiency has risen dramatically in the last few years. There is, however, a bewildering array of ways that these components can be assembled into a system.

(6) The common "generic" types of HVAC systems respond to different variations of loads in different, poorly understood ways. Recent research has shown that in some buildings replacing one type of HVAC system with another type with essentially identical steady-state efficiency, can change the building's annual energy consumption by 30%! This appears to be due to highly nonlinear system responses to part-load or varying-load conditions. A scientific understanding of this issue is lacking.

5. Systems Interactions

A modern commercial building is startlingly similar to a living organism; all of its environmental conditioning systems are highly interactive. For example, the lighting system affects the HVAC system due to its heat output. Conversely the temperature of a flourescent lamp system affects its light output. System efficiency falls dramatically below or above temperatures around 75°F. (This can be seen in any unheated garage on a cold winter night.) As another example, a HVAC system that blows air across a window changes the conductivity coefficient of the air film next to the glass and thus the window's net conductivity, which in turn changes the load on the HVAC system. These system interactions are only beginning to be investigated. As they become understood, building designers will be able to assemble environmental systems in ways that cause them to operate synergistically rather than antagonistically. As well, control system manufacturers will be able to devise control systems that optimize building system performance. At the present time control systems are generally designed to assure that there are no complaints from building occupants; energy consumption tends to be a minor consideration.

5. Conclusions

Since the end of World War II many improvements have been made in the components that provide environmental comfort to humans in buildings. We are able to provide reasonable air temperatures and humidities, and adequate amounts of light. We often can provide a very comfortable and pleasing environment as well although we often don't know how we did it, in quantitative terms amenable to replication. There are fewer than 40 commercial buildings whose energy consumption has been measured in a detailed, scientifically useful way.

We generally accomplish the above at the expense of a substantial consumption of energy, when it is unclear that this consumption is necessary. To put this in perspective, consider that a fairly well-designed office building in Washington, DC consumes approximately 75,000 BTU/ft^2/year for thermal conditioning and lighting. However, this building receives 440,000 BTU/ft^2/yr of solar energy, on the average. The point is that the environment appears to have much more potential as a source of energy than it is given credit for. Environmental energy sources tend to be spatially or temporally removed from the building's energy needs. (E.g. sunlight on the roof vs. lighting needs in the building core, or winter frozen ground vs. summer air-conditioning loads.) Buildings are not designed to transfer energy from system to system or season to season in a simple, elegant manner.

Some designers are starting to create "climate-adaptive" rather than "climate-defensive" buildings. These buildings make use of daylight, natural ventilation and other environmental sources to provide human comfort. They do not isolate humans from the outside world yet provide much better comfort than turn-of-the-century daylit buildings. Documented, measured data (7) indicate that they consume far less energy than conventional buildings at a zero to 5% increase in average first cost. More important is the fact that occupants like these buildings. They like the natural light and the feeling of open space and connection to the outdoors. Experimental climate-adaptive buildings that were built in research programs under the author's direction, that were public buildings (community colleges, banks, engineering/sales offices, libraries) experienced far higher occupancies

than the owners had anticipated. Qualitative though it may be, this is the best measure of value in a building. We are beginning to know how to design good buildings.

Notes:

1. Residential energy problems and solutions particularly for cold climates, are thoroughly discussed in *The Passive Solar Energy Book,* Edward Mazria, Rodale Press, 1979. This text was written for the intelligent layman as well as home designer or builder and is possibly the best-selling technical book in history, at over 300,000 copies.
2. *State Energy Data Report, Consumption Estimates, 1960–1983,* Energy Information Administration, May, 1985, page xxi.
3. A good discussion of the history of solar energy use in buildings is contained in *The Golden Thread: 2500 years of Solar Architecture and Technology,* Ken Butti and John Perlin, Cheshire Books and Van Nostrand Reinhold, 1980.
4. An interesting description of the emergence of modern building mechanical systems is contained in Chapter 2 of *Energy Conservation Through Building Design,* Donald Watson, McGraw Hill, 1979.
5. An excellent text discussing alternative design philosophies and options is *The Design of Energy-Responsive Commercial Buildings,* Solar Energy Research Institute, John Wiley & Sons, 1985.
6. For more information of HVAC systems, see ''Air Conditioning Systems: An Overview of Operating Principles and Features'', William Tao, *Building Operating Management,* December, 1983.
7. ''Lessons Learned from DOE's Commercial Passive Solar Buildings Program'', William J. Fisher and Alexander Shaw, *Architectural Technology,* Fall 1984.

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Small-scale Cogeneration at Military Installations in the United States*

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ABSTRACT

Military installations in the United States provide significant potential for cogeneration. These potential applications, however, carry unique characteristics and requirements that must be addressed in order to promote the successful development of this market. In this paper, the authors will present a discussion of this market, and the unique properties and characteristics of cogeneration at military installations, including incentives, disincentives, and potential financing concepts.

Introduction

Military bases are large consumers of energy, particularly electricity. As a consequence, military installations are faced with high energy costs, including substantial demand charges for electric service. The existing profile of military installations presents some interesting and promising prospects for small-scale cogeneration. Since military installations generally have been developed over a period of time, they contain many facilities that are isolated from the installation's central heating/cooling plant, and hence, require individual energy systems. These buildings are used for a variety of purposes, some of which are favorable for cogeneration. Buildings such as hospitals, dining halls, community centers, gymnasiums, barracks, and family housing require both electrical and thermal energy, providing a good opportunity for the application of small-scale cogeneration systems. Such applications could benefit the military services by promoting:

* Military operations cost savings;
* Utility capacity expansion deferrals;
* Fossil fuel savings, particularly petroleum fuels, that would have been used to produce cogenerated thermal energy;
* Secure electric and thermal energy to meet an Installation's requirements; and
* A means for the military to meet their congressionally mandated energy reduction goals.

Interestingly, few small-scale congeneration systems have been installed or are cur-

*Presented at the 5th International Cogeneration Society Conference, October 1985.

rently operating at military bases in other than demonstration or experimental programs, in spite of what appears to be a good market. This apparent paradox presents an interesting example of how a technology that in many respects receives favorable legislative and regulatory treatment on both the federal and state levels is somehow derailed in its introduction to and penetration of the Department of Defense (DoD) market. There are two major obstacles that discourage the utilization of small-scale cogeneration systems in the military: current DoD procurement practices and the evaluation procedures used to analyze DoD energy projects.

In this paper, the authors will examine the market for small-scale cogeneration, existing incentives for cogeneration, and the factors discouraging its use in the military. In addition, we will provide a sample evaluation of cogeneration at a military installation to demonstrate how it is evaluated in the military vs. how it is evaluated in the private sector. Finally, we will discuss the prospects for small-scale cogeneration in the military and how they may change.

Cogeneration Potential in the Military

The potential for cogeneration at military installations can be defined in terms of the need for energy conservation and the ability of the technology to address the unique characteristics of the DoD market. An appreciation for the size of the market for cogeneration in the Army, Navy, and Air Force can be gained by looking at their energy consumption. In the aggregate, the DoD accounts for approximately *82 percent* of the *total* U.S. Government energy consumption. This figure includes shore facilities, ground support, aircraft, and ships. In Fiscal Year 1983 (FY1983), this amounted to 1,481 Trillion Btu (TBtu). While detailed assessments of cogeneration potential have not been performed, available data do offer some insight into the size of this market.

A further examination of the energy profiles of the Army, Navy, and Air Force illustrates the distribution of energy consumption. Table 1 and Exhibit 1 provide a breakdown of energy consumption for shore facilities operations by fuel type for the Army, Navy, and Air Force in FY1983. Total shore facility consumption of 556 TBtu represents 38 percent of total DoD energy requirements and 0.8 percent of total U.S. consumption. Electricity consumption represents over 50 percent of DoD shore facility requirements. On an aggregated basis, this energy profile suggests that cogeneration might be appropriate, given the high electricity consumption, as well as the significant amounts of fossil fuels burned for thermal energy.

In addition to offering the benefit of energy savings, cogeneration can provide the military with secure, on-site energy for their bases. Such installations could include communications stations, medical facilities, and command/control facilities, which require independent power sources to reduce their vulnerability to power outages.

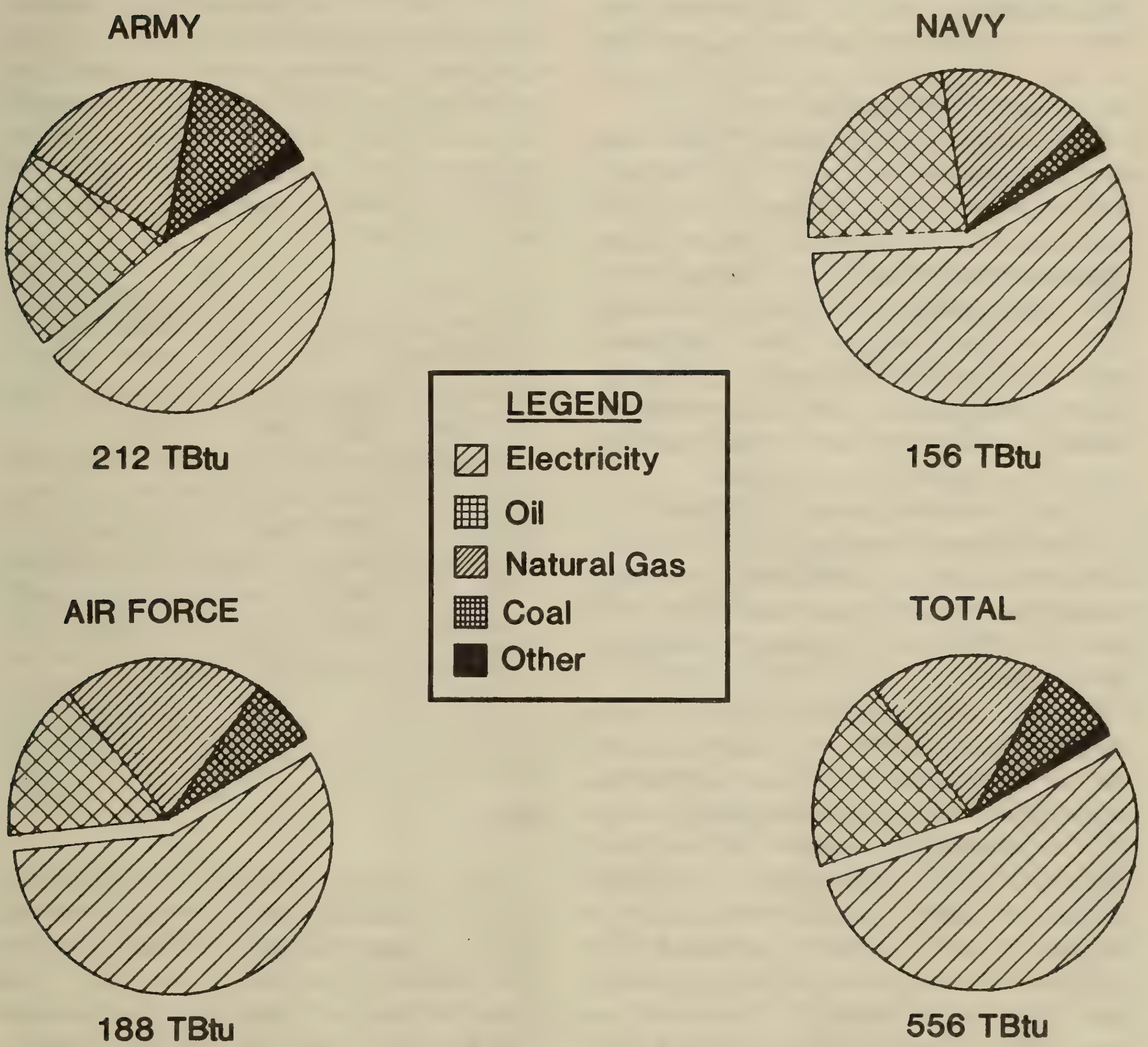
Although military bases resemble other institutional complexes, there are a number of unique characteristics that make this market different from commercial or industrial cogeneration markets. Four primary characteristics must be considered in small-scale cogeneration system applications. These include:

* *Functions*—Individual base and building mission, base configuration, geographic location, size, and energy use profiles;
* *Energy Security*—Overall national security and emergency preparedness, as well as assurance of secure and uninterruptible power supply backup;

Table I.—Fiscal year 1983 Shore Facilities Energy Consumption

		(TBtu)		
Fuel Type	Army	Navy	Air Force	Total
Electricity	100	90	106	296
Oil	43	36	30	109
Natural Gas	40	25	38	103
Coal	25	4	13	42
Other	4	1	1	6
Total	212	156	188	556

Exhibit 1
DEPARTMENT OF DEFENSE
SHORE FACILITIES ENERGY CONSUMPTION
FY 1983



* *Energy Conservation Mandates*—As federal buildings, military facilities are required to reduce overall consumption, particularly petroleum fuels, by 20 percent in relation to 1975 consumption levels; and
* *Procurement Practices*—Federal procurement actions must be based on life-cycle costing as a primary decision criterion.

Currently, three of these characteristics—functions, energy security, and energy conservation mandates—act as incentives for small-scale cogeneration applications at military installations. However, current procurement practices serve as barriers to its use. These incentives and disincentives are further described in the following sections.

Incentives for Cogeneration

Within the federal government, there are several legislative and regulatory mandates that promote cogeneration for the military, as

well as for other federal agencies. These mandates include the Public Utilities Regulatory Policy Act of 1978 (PURPA), the National Energy Conservation Policy Act (NECPA), and the National Energy Plan. In addition to these mandates, there are the standard benefits of cogeneration, such as energy and cost savings, utility capacity expansion deferrals, and secure energy supplies.

The incentives provided by PURPA have only recently been realized by the military. The authority for the military to sell power to utilities, consistent with PURPA, was granted by Public Law 98-407, on August 28, 1984. Until then, military installations did not have clearly defined authority to sell power at avoided cost. This recently granted authority now provides the military with the same incentives extended to other qualifying facilities to promote cogeneration.

Energy conservation goals for the federal government have been established by NECPA. NECPA requires the installation of low-cost/no-cost energy conservation retrofits, by 1990, in all federal buildings with over 1,000 square feet of floor area.

The National Energy Plan (NEP), which defines the nation's energy strategy, includes the overall objectives of reducing dependence on foreign fuel, limiting vulnerability to supply disruptions in the near term, and developing renewable and essentially inexhaustible sources of energy for long-term sustained economic growth. Specific goals cited in the NEP include a reduction in energy consumption in federal buildings by 20 percent per square foot in existing buildings and 45 percent per square foot in new buildings, based on FY1975 consumption levels.

The DoD is the largest energy-consuming federal agency, with over 400,000 buildings and 2.4 million square feet. These buildings account for approximately 69 percent of energy consumption in all federal buildings. By the end of FY1983, the Department had achieved a 13.7 percent reduction in Btu per square foot in comparison to 1975 levels. This was accomplished through the combined efforts of all three branches of the military, as mandated by their respective energy plans, which are outlined below.

Army

The Army accounts for approximately 18 percent of DoD energy consumption, of which almost 83 percent is consumed by shore facilities operations. The facilities' energy consumption goal for FY1985 is 203.3 TBtu—a 16 percent absolute reduction in total consumption from 1975 levels, and the level at which the Army will achieve the 20 percent per square foot savings goal required by the NEP. In addition, the Army's long-range consumption goals are to:

* Reduce overall energy consumption by 35 percent by the year 2000 from 1975 levels;
* Reduce dependence on nonrenewable and scarce fuels by the year 2000;
* Reduce the use of natural petroleum fuels in facilities operations by 75 percent by the year 2000 from 1975 levels;
* Attain a position of leadership in the pursuit of material energy objectives; and
* Achieve both near- and long-term goals without degrading readiness.

Navy

Like the Army, the Navy has established a goal of reducing overall energy consumption by 35 percent below 1975 levels by the year 2000. In approaching these goals, Naval shore facilities have reduced their consumption from 286.1 $\times$ 10^3 Btu/sq. ft. in 1975 to 257.8 $\times$ 10^3 Btu/sq. ft. in 1981, an overall savings of 9.9 percent. One major Naval conservation activity is the Energy Conservation Investment Program (ECIP), which provides for improvements, alterations, and the upgrading and repair of existing buildings and utility systems to reduce energy consumption. Although the program's projects generally include the more traditional retrofit activities for energy conservation (low-cost/no-cost measures), it can also include cogeneration applications. In fact, the Navy is the lead DoD service for cogeneration and is responsible for coordinating R&D efforts and de-

veloping funding and contractual mechanisms for cogeneration. To date, the Navy has completed 21 cogeneration feasibility studies, and the Naval Civil Engineering Laboratory is developing guidelines for the application of small-scale cogeneration systems. The FY1983 Navy Energy Plan estimates that savings achievable by small cogeneration systems can be substantial.

Air Force

In FY1983, the Air Force showed a decrease in energy consumption of 14.9 percent per square foot over 1975 levels. Projections in the 1985 Air Force Energy Plan indicate that reductions in building energy use will continue to approach the goal of 35 percent by the year 2000. The Air Force's energy supply goals include reducing petroleum fuel use 35 percent by 1990 and 45 percent by 2000, and increasing the use of coal and renewable sources. Further, the 1985 Air Force Energy Plan establishes a framework for achieving these goals by implementing specific energy conservation strategies and activities.

Disincentives for Cogeneration

The success of small-scale cogeneration at military installations is not dependent solely on the advantages discussed in the preceding section. If it were, one would expect to find numerous small-scale cogeneration systems in the military. First, there are two major impediments which have hindered the installation of these systems. These are the contractual limitations imposed by the military procurement system and the evaluation methods used by DoD for assessing cogeneration feasibility. In addition, a significant barrier to the adoption of cogeneration in the military is the shortage of personnel to install, operate, and maintain the equipment. This situation enforces energy use patterns which may be expensive, but which are appropriate when constrained by manpower scarcities.

Military Procurement System

The existing DoD procurement system is not conducive to fully realizing the true market potential of small, modular cogeneration systems. The current system is overburdened with institutional barriers, rules, and regulations established for purchasing weapon systems and other related military hardware—not energy systems or services. Contract terms required by the military procurement system have hampered the ability to achieve energy conservation goals with small-scale cogeneration.

DoD installations are required to procure energy systems in one of two ways: either by applying directly for Military Construction Funds (MILCON), or through a two-step procurement process outlined in each of the services' energy plans. MILCON funds are used for all major military construction projects, such as road improvements, air field construction, and building construction. They are appropriated based on a project's overall military and mission-specific value, and life-cycle cost. As a result, it is very difficult to justify funding for an energy system from the MILCON budget, especially for a small cogeneration system. To date, the only energy projects that have been installed using MILCON funds have been large central plants.

The most common alternate procurement strategy for purchasing energy systems is the use of funding mechanisms established in the energy plans. The first step in the process is to conduct a feasibility study to assess the economics of a proposed project based on DoD life-cycle costing procedures. At the end of each fiscal year, feasibility studies are ranked by each service according to their Savings-to-Investment Ratio (SIR—the ratio of discounted project savings to total investment). Low-cost/no-cost projects will generally achieve the best SIR under DoD's analysis procedure, due to their small capital outlays.

These projects are the first to be funded by construction/installation awards. Since the number of low-cost/no-cost projects that qualify for funding is greater than the number of potential small-scale cogeneration projects, construction funds are generally allocated to low-cost/no-cost projects. Therefore, few, if any funds are available for higher-cost projects such as cogeneration.

Alternative Procurement Strategies

An alternative methodology for tapping the DoD small-scale cogeneration market is through creative financing. Under this strategy, an investor, such as a private energy company, invests capital to design, construct, retrofit, and/or operate and maintain a facility's energy systems. In exchange, the investor receives a commitment from the particular installation to purchase energy or share in the energy cost savings produced from the project. The investor also receives all the depreciation, energy, and investment tax credits applicable to the particular investment. These strategies limit the amount of risk to the government by placing most of the contractual and financial responsibilities on the third party. However, current procurement regulations prevent the DoD from entering into a service contract that is greater than five years. This places excessive financial risk on the third party by not allowing sufficient time to recoup the investment. Most private companies involved in creative financing will not enter into such agreements for terms of less than seven years.

Although creative financing strategies are viewed as service contracts by the private sector, DoD views them as equipment procurements subject to a one-year contract to be paid over several years, with only some features of a service contract. This increases the risk to potential investors and, for cogeneration, limits the possibilities even further.

Another advantage to the military with third-party financed cogeneration is the inclusion of installation, operation, and maintenance services as the third party's responsibilities. In many cases, this not only permits the alternative deployment of military personnel but can also provide a greater incentive to base managers.

To date, DoD has expressed a strong interest in creative financing strategies, such as shared savings and third party financing. This can be seen in the energy plan developed by the Navy. The DoD has chosen the Navy to pioneer shared savings for the military. However, the Navy's first few energy-services/shared-savings requests for proposals (RFPs) have run into the roadblocks outlined above. In order to improve the DoD environment for creative financing, the Navy has submitted a proposed amendment to the FY1986 Military Construction Authorization Bill to both the House and Senate (H.R.1409 and S.537) which would give the military the authority to enter into 30-year shared-savings agreements, including the purchase of both energy services and equipment.

In an effort to improve procurement procedures for shared-savings programs, the Navy prepared draft Requests for Proposals (RFPs) which were reviewed by the authors of this paper. The RFPs had a number of restrictions that made shared savings extremely unattractive to a potential investor. The RFPs severely reduced the incentives for an investor to take the risks that are inherent in shared-savings propositions. More specifically, the proposed RFPs declared that tax benefits, one of the key benefits of shared savings, would be deducted from energy savings estimates as a Treasury offset. Thus, any company proposing capital-intensive measures such as cogeneration would be penalized. Second, the proposed RFPs did not allow demand savings for the contractor, and one of the major benefits of cogeneration is demand reduction. Hence, this technology is further penalized by the DoD. The proposed RFPs have since been modified to reduce the risk to an investor, and are scheduled to be released when the Military Construction Authorization Bill is passed. The modifications made to the model RFPs include the allowance of tax benefits and the flexibility to include demand charge savings for the contractor.

Therefore, although the DoD procurement system currently is a disincentive to small-scale cogeneration applications, methods for remedying the situation are being considered.

DoD has not only recognized that there is a high potential for small-scale cogeneration on military installations, but also that current systems for the procurement of traditional military equipment do not meet the needs of energy conservation equipment. Hence, it is likely that, in the near future, this major barrier will be eased, allowing for substantial growth in the DoD small-scale cogeneration market.

Evaluation Methods

The first step in the existing ECIP methodology specifies that potential investments are to be evaluated on a life-cycle cost basis. By DoD definition, this method limits the consideration of cost savings based on demand reduction—the primary benefit of cogeneration. Therefore, the DoD life-cycle cost evaluation method penalizes cogeneration projects by not considering all of the potential savings.

For example, the rate structures of utilities for military installations generally include a high peak demand charge. These demand charges often account for a significant portion of an installation's total electric bill, sometimes as much as 60 percent. By reducing the load placed on the utility system with cogeneration, the installation can realize substantial savings from reduced demand charges. However, the DoD life-cycle cost algorithms do not allow for the inclusion of 100 percent of these savings or for capacity credits which the utility may provide under avoided costs. Similarly, a cogeneration system may reduce thermal energy costs by displacing central plant steam loads with more efficient cogenerated steam or hot water. As with demand charge savings, 100% of these cost savings are not considered in the life-cycle cost calculations used for military installations.

Military Evaluation Procedures Example

To demonstrate the impact of the military procurement system on the evaluation of small-scale cogeneration, a case example is presented. In this example, a 320-kW diesel-fired cogeneration system at a Naval installation will be evaluated using actual building load data, fuel prices, and other assumptions in accordance with Navy ECIP specifications. As this example will show, under DoD evaluation procedures the cogeneration system is not an attractive option. However, with life-cycle costing methodologies commonly used in the private sector, *excluding* tax benefits (e.g., ITC, ETC, and depreciation) and debt financing, the same cogeneration installation becomes attractive.

Exhibit 2 provides the assumptions used in this analysis. It should be noted that, except for system specifications, fuel prices, and utility rates, these assumptions are those used for evaluating energy conservation projects in the Navy. For consistency, these data assumptions will be used in both the military and private-sector evaluations.

One very significant assumption in this analysis is the absence of power sales to the grid. Since DoD facilities only recently received the authority to sell power to utilities, the DoD evaluation methodology used in this example does not allow power sales to be considered in the analysis. Hence, it is assumed that all electrical and thermal outputs from the cogeneration system are used to satisfy energy requirements at the installation. This displaces purchased electrical and thermal loads.

For this evaluation, the total investment cost of the cogeneration system is $224,000, which includes design, installation, supervision, inspection, and overhead. The purchase of the system is on a cash basis, paid in the first year. The system is fully installed and operational in the first year.

In the DoD/ECIP life-cycle cost analysis, the primary objective is energy savings. As a result, other benefits such as demand charge savings or other non-energy savings are limited to 25 percent of the total savings. As mentioned, ECIP projects are ranked on the basis of life-cycle cost and payback, and are quantified in a SIR. A SIR of greater than one means the investment is cost-effective (the higher the ratio, the greater the dollar savings per dollar invested). Generally, the Navy's ECIP-funded projects have been low-

Exhibit 2—Sample Cogeneration Evaluation Assumptions

SYSTEM SPECIFICATIONS
—Fuel Type: Diesel
—Capacity: 320 kW
—Fuel Consumption Rate: 23.5 gal/hr
—Recoverable Heat: 1.257 MMBtu/hr
—Installed Capital Cost: $224,000
—Operating & Maintenance Cost: $3,360
—O&M Escalation Rate: 0%
—Capacity Factor: 0.85
—System Life: 25 years
—Discount Rate: 7%

FUEL DATA
—Diesel Heating Value: 138,700 Btu/gal
—Diesel Price (Base Year): $4.97/MMBtu
—Diesel Escalation Rate: 8%/yr
—Coal Price: $2.50/MMBtu
—Coal Escalation Rate: 5%/yr
—Electricity Price: $5.17/MMBtu
—Electricity Escalation Rate: 7%

BUILDING LOADS
—Thermal Energy Requirements: 378.29 MMBtu/yr
—Electrical Load: 255 kW
—Electricity Requirements: 450,000 kWh/yr

cost, no-cost programs, with SIRs greater than fifteen.

Net energy savings consist of displaced electrical and thermal energy, minus the energy used to operate the cogeneration system. In this example, the annual electrical energy displaced is 27,640 MMBtu, for a total annual savings of $142,896 (adjusted for generation, transmission, and distribution losses). The total discounted electric energy savings amount to $2,069,141 over the system life. Thermal energy savings amount to 9,360 MMBtu/year. Based on coal-fired generation, total discounted thermal savings amount to approximately $485,000. Fuel costs for the cogeneration system, discounted over the system life, are $2,127,758. Thus, net discounted energy savings are approximately $426,000.

Discounted net non-energy costs (O&M) are $5,848. Thus, the total net discounted savings are approximately $420,000. Using this figure, the SIR is 1.78. While greater than one, the SIR would not justify the commitment of funds under ECIP. This SIR translates to an internal rate of return (IRR) of 26.55 percent.

In the private-sector analysis, which does include demand charge savings in net cash flows, the IRR is 35.28 percent. This example illustrates that the DoD ECIP evaluation procedure does not allow for a comprehensive consideration of the benefits of cogeneration, particularly in regards to power sales and non-energy savings. As such, cogeneration is limited by the evaluation process.

Conclusions

The prospects for small-scale cogeneration at military installations do not end here. There is a growing recognition of the value of cogeneration to the military. The most promising avenues for cogeneration include the use of third party financing and shared savings. As was discussed earlier, these methods offer the necessary incentives for private investors, while providing the military with cost and energy savings. Currently, the military has authority to enter third party contracts. The procurement process, however, needs to be

streamlined to improve the viability of such arrangements.

The first important step in developing the military cogeneration market was the recent authority given to DoD to sell electric power to utilities. In addition, there is legislation that has been proposed in amendments to the FY1986 Military Construction Authorization Bill (H.R.1409 and S.537) which would authorize a two-year test plan for shared-savings programs. The proposed amendment would give the military the authority to sign 30-year contracts specifically for energy savings. This would include construction, utilities, supplies, and services. The service aspect is particularly attractive to the military, because it would not require the deployment of additional personnel for operation and maintenance of cogeneration facilities. The prospects for this legislation are quite favorable.

The successful penetration of small-scale cogeneration in the military has not yet occurred. Recent and upcoming developments may change that trend. For those companies adept at military procurement practices and shared savings/third party financing, or with access to these qualifications, the future holds great promise.

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Photovoltaic Higher Education National Exemplar Facility at Georgetown University

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Introduction

The energy from the sun falling on the surface of the earth for two weeks is equal to all the energy in an optimistic estimate of the world's original supply of fossil oil.[1] Since sunlight is virtually inexhaustible, it is a very attractive candidate for an alternate energy source. One area of intensive research and development is the use of solar cells to convert sunlight into electricity directly. Loferski[2] has estimated that 10% efficient solar cells on most of the rooftops in the United States could supply all the nation's energy needs. The incident solar power at sea level on a sunny day when the sun is directly overhead is almost 1000 Watts/Meter.[2] The physical mechanism by which solar energy is converted directly into electrical energy by the solar cell is the photovoltaic effect. The solar cell is essentially a p-n junction i.e., a p-type semiconductor and an n-type semiconductor with no external bias voltage. When the solar photons are absorbed, each photon creates an

electron and a hole. When these carriers diffuse to the junction, the built-in electric field of the junction sweeps them down the energy barrier. This separation of the carriers produces a forward voltage across the barrier because the electric field of the photo-excited carriers is opposite to the built-in field of the junction. The appearance of this forward voltage across an illuminated junction is called the photovoltaic effect.[3] So an illuminated junction can deliver power to an external circuit. Large area p-n junctions of silicon can be used to convert solar photons to electrical energy. The research and development work is directed toward exploring various materials from which p-n junctions can be made which will give maximum efficiency in the solar energy to electricity conversion at minimum overall cost. Single-crystal Silicon has been studied extensively and, in the laboratory, under carefully controlled conditions, the theoretical limit of conversion efficiency of about 22% is being approached but there is still an excessive amount of energy wasted in the process.

In the photon absorption process, only those photons whose energies are greater than the bandgap of the material will be absorbed. Silicon has a bandgap of 1.1 eV so all photons whose wavelengths are greater than 1.13 um are not absorbed but pass through the material. At the same time, photons with wavelengths shorter than 1.13 um will not contribute effectively to the electrical output and their energy is basically lost by conversion to heat. Zalewski and Geist[4] estimate these losses for Silicon at 24% as bandgap loss and 32.5% as heat loss which means that more than half of the available solar energy is lost. In order to overcome some of these losses, research is aimed at exploring other thin film junctions using materials whose bandgaps are near the point where the sun's spectral radiance is greatest (400–700 nm). Another technique is the use of cells of different materials bonded together in a cascade of layers, each layer having a different bandgap. Solar photons with high energy are captured in the high bandgap first layer and the lower energy photons pass through the first layer but are captured in the several layers of lower bandgap material. By repeating this process, a multi-layered solar cell is theoretically possible. Loferski[2] has calculated an efficiency of 43% for a seven layer cascade or tandem cell. Practically, however, only three or four layer cells appear to be realizable due to other interface losses in such a device. Materials such as Ge, $CuInTe_2$, $CuInSe_2$, CuS_2, InP, GaAs, CdTe, $CuInS_2$, Cu_2O, Se, GaP, and CdS are under active investigation. But about half of all R & D money spent on photovoltaic research goes to amorphous silicon because of its relatively low cost and ease of volume production. Amorphous silicon has dramatically different properties from single crystal silicon. Instead of a bandgap of 1.1 eV, hydrogenated amorphous silicon (α-Si: H) has a bandgap of 1.6 eV and the cells can be made much thinner than single crystal-silicon cells.

Government Program

Even though it is apparent that the need for alternate energy sources will continue to increase indefinitely, engineering firms are reluctant to commit large amounts of capital in techniques that are not proven. To encourage the industry to pursue novel ideas, the Department of Energy began sponsoring projects ranging from research and development on solar cells to actual solar power systems. Contracts are channeled through the Solar Energy Research Institute, the Jet Propulsion Laboratory, Sandia Laboratories, NASA Lewis Research Center and MIT Lincoln Laboratory. The ultimate goal is to achieve solar systems that will be competitive with coal and petrochemical systems for producing electrical energy. The 1986 goal is solar cells that cost no more then \$0.70 per watt of electrical power produced and solar cell arrays that cost no more than \$2.20 per watt compared to present costs of about \$6 per watt per cell.

The photovoltaic Higher Education National Exemplar Facility at Georgetown University is a part of this program.

Solar Collectors

The simplest arrangement for collecting large amounts of solar energy is to combine many

individual solar cells together in a flat-plate array. The individual solar cells are connected together electrically in series and parallel groups to obtain the desired voltage level and power output. The array must face the sun and be inclined to the horizontal at an angle determined by the latitude. It is not necessary to have the array track the sun because the cells are non-directional and receive energy over the entire forward hemisphere. Since the electrical output is proportional to surface area of the solar cells, many cells are needed for a large electrical power system. Assuming an array with a 10% conversion efficiency, 100 m^2 of solar cells are required to produce 10 KW of electrical power. Each group of series and parallel cells is called a module and a number of modules are assembled together in a large unit called a panel. A standard panel might be composed of a vertical configuration of 2, 4, 8, or 12 modules. The panels are then used to form the array and usually mounted on a south facing roof inclined at the proper angle by a rigid mount attached to the roof. Rectangular solar cells are used to optimize the area of exposure per panel.

Since single crystal solar cells are expensive, techniques have been developed for concentrating the sunlight onto fewer cells. The "concentrator" may be, for example, a flat, circular Fresnel lens which can be pressed out of acrylic plastic in sizes up to at least 1 ft^2 and are relatively inexpensive. The concentration ratio is defined as the ratio of the lens area to the solar cell area. Concentration ratios of 500 are easily achieved. One problem with concentration cells is the large amount of heat generated which raises the temperature of the solar cell. Since solar cell efficiencies drop with increasing temperature, the cell must be cooled. So the cells are mounted on a heat sink through which a coolant liquid is circulated.

Obviously, both the Fresnel lens and the coolant system add to the cost of the array. In addition, the Fresnel lenses must point accurately at the sun and a two axis motorized mount and sun sensor must be provided. A number of variations have been tried such as domed Fresnel lenses, linear Fresnel lenses and arched linear Fresnel lenses. Parabolic reflecting troughs with the solar cells down the focal line of the trough have also been built. In many of the concentrator class solar cells, the heated coolant fluid is used to provide the working fluid for heating or cooling the building interior and this process is called "cogeneration".

Table I.—Solarex cell characteristics.

Dimensions	9 cm × 9.5 cm
Efficiency	11.6%
Power	1.00 Watt
Maximum Voltage	0.458 Volt
Maximum Current	2.18 Amperes

The Georgetown Facility

The Intercultural Center at Georgetown University was designed specifically to accommodate the Photovoltaic array. The building was oriented so the roof faced south and the roof sections were oriented at the proper angle with respect to the vertical so that maximum solar energy would be collected.

The solar cells are manufactured by Solarex. Table 1. lists the cell characteristics.

Each module incorporates 72 of these solar cells. The array field is divided into twelve subfields for reasons of control, analysis and optimization of wire sizes. It consists of 4296 active modules divided into twelve subfields and 179 parallel strings of 24 modules in series. Table 2. shows conservative estimates of the module performance characteristics.

When the modules are connected together to form the array, there are inevitable losses due to mismatched module impedances and conductor, diode shunt losses. Table 3. shows the data on the overall array.

Table II.—Module performance characteristics.

Power	72 Watts
Voltage	20.2 Volts at 1.5 Amp
Current	4.7 Amp at 100 mw/cm^2
Voltage at Max Pwr	16.50 v @28°C
Current at Max Pwr	4.37 Amp
Efficiency	11.6%

Table III.—Array Specifications.

A. Area of One Module	0.675 m^2
B. # of Modules in Array (24 Modules/String @ 360 v Nominal)	4454 with 4296 Active
C. Roof Area Occumpied by Array	3271 m^2 with 3155 m^2 Active
D. Module Packing Factor	0.92
E. Module Mismatch Losses	1%
F. Conductor, Diode, Shunt Losses	2%
G. Average Module Power Output	72 Watts
H. Design Array Power Output	300 kw
I. Module Efficiency	10%

Figure 1 shows the roof configuration for the array.

The system operates in parallel with the local power utility (PEPCO) so the DC power generated by the Photovoltaic array must be inverted to AC by means of a power conditioning system which includes a maximum power tracker and a 300 KVA inverter which fully complies with PEPCO interface requirements. Provisions are made to shutdown the PV system in case of utility outage. Figure 2 is a simplified block diagram of the complete system.

The power sensing circuitry includes an ON-SITE DATA ACQUISITION SYSTEM COMPUTER to collect data needed to monitor the performance of the photovoltaic array. Other data is collected on power shutdowns, failures, array cleaning or adjustments or testing which may temporarily reduce system output.

Monthly status reports are generated from these data and include the following parameters:

a) Total solar energy incident on the array.
b) Total DC energy produced by the array.
c) Total AC energy output by the power conversion unit.
d) System efficiency.
e) Power conversion unit efficiency.
f) Hours of operation.
g) Rated power of the array at normal operating cell temperature.

Results

The Georgetown facility was brought on line in September 1984. Normal system start-up problems were experienced and appropri-

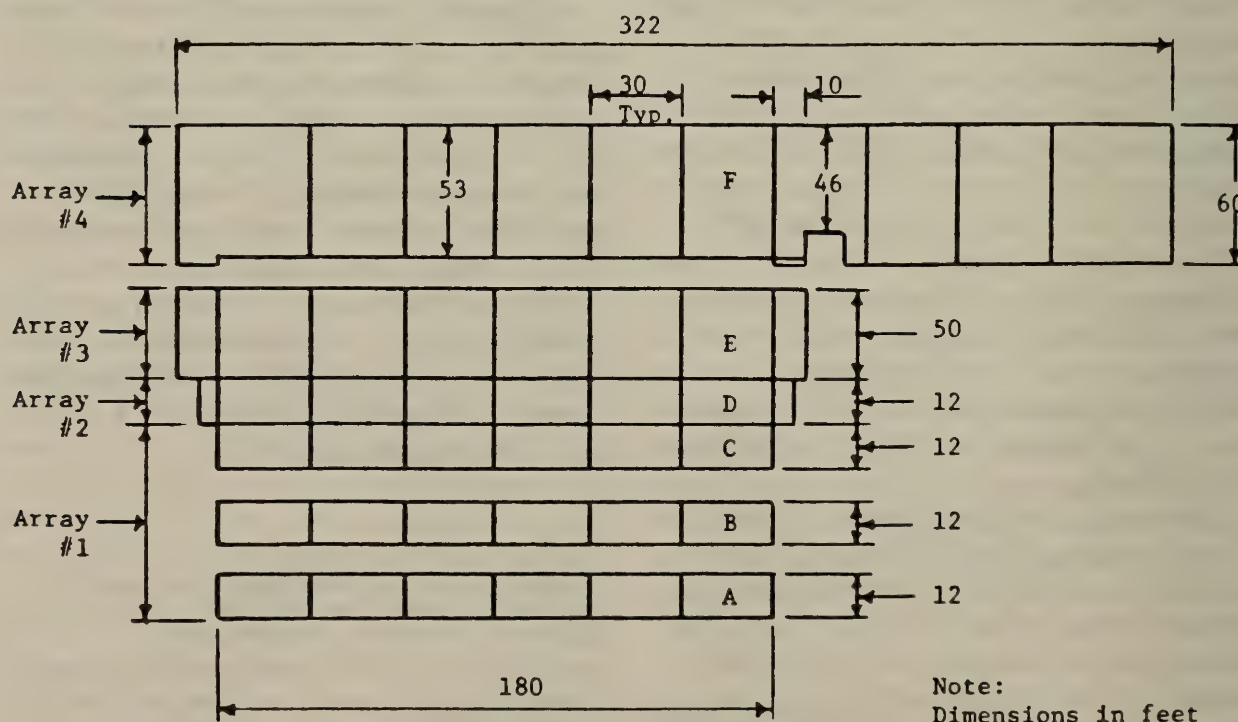

Fig. 1 Roof configuration and array nomenclature

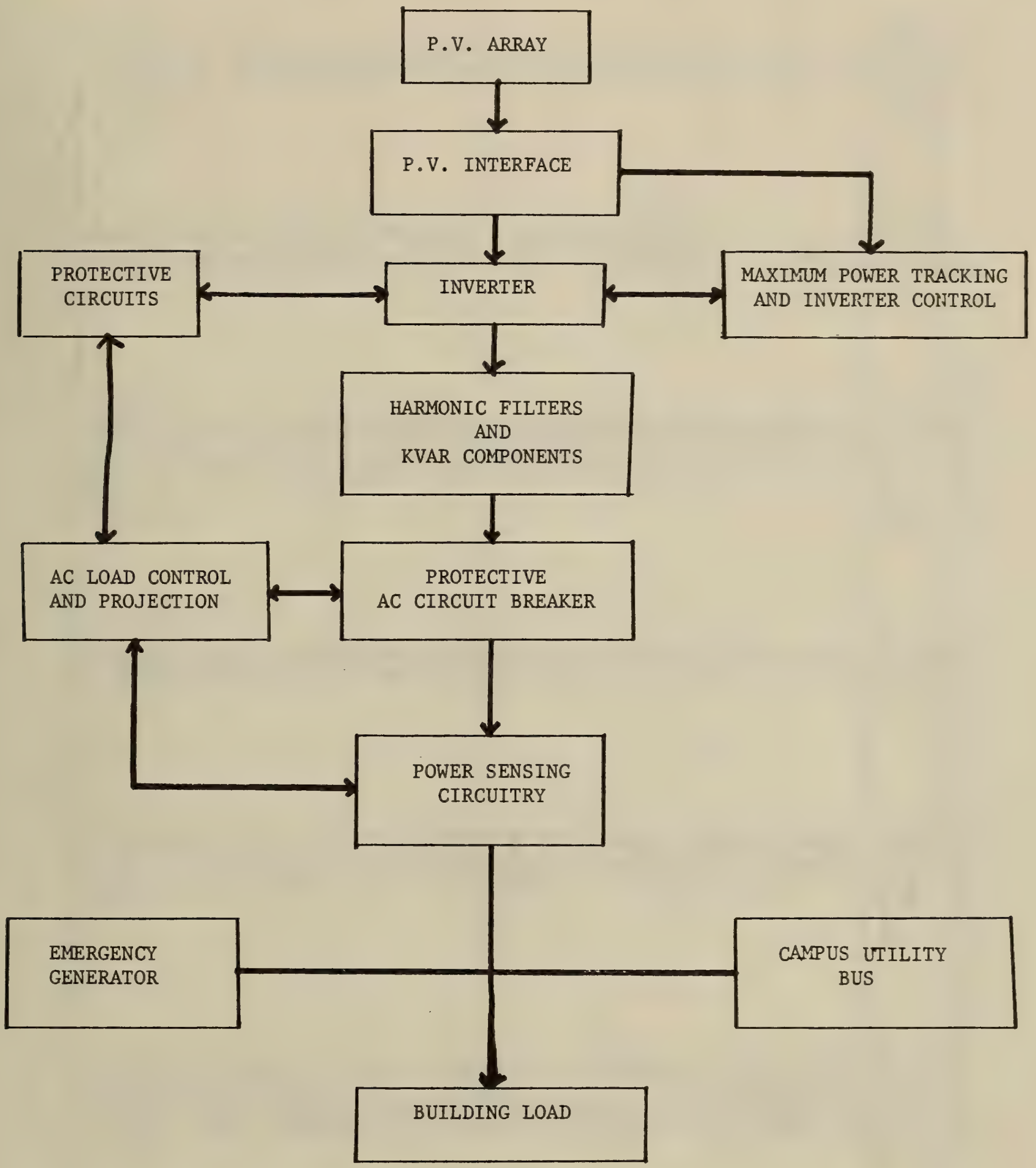

Fig. 2 System block diagram

ate corrective measures were taken. Boeing Computer Services collects the data on the entire photovoltaic array. The data is transmitted to Science Applications International Corporation on a daily basis where it is reduced to provide the monthly status report. Tables 4 through 8 are the performance summary charts for November and December 1984 and January through March 1985. The charts summarize the major important characteristics of the operation of the photovoltaic array on a daily basis. The first column represents the day of the month. The second column shows the total number of hours that the power

Table IV.—Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of November, 1984.

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	0.00	3286.38	0.00	0.00	0.00	*	*
2	0.00	3569.24	0.00	0.00	0.00	*	*
3	0.00	17469.04	0.00	0.00	0.00	*	*
4	0.00	7596.40	0.00	0.00	0.00	*	*
5	0.00	269.38	0.00	0.00	0.00	*	*
6	5.50	10909.72	347.00	3.18	304.00	87.61	*
7	8.67	19354.68	1125.00	5.81	1077.00	95.73	273.0
8	9.67	17671.07	1329.00	7.52	1274.00	95.86	274.7
9	9.50	14775.26	1114.00	7.54	1067.00	95.78	279.9
10	9.83	15394.84	1158.00	7.52	1112.00	96.03	270.8
11	5.33	2909.26	159.00	5.47	141.00	88.68	*
12	7.83	6963.36	947.00	13.60	912.00	96.30	270.7
13	8.17	2074.19	436.00	21.02	402.00	92.20	*
14	9.83	19704.86	1506.00	7.64	1449.00	96.22	270.9
15	9.17	10775.04	775.00	7.19	737.00	95.10	263.9
16	9.17	11421.53	828.00	7.25	790.00	95.41	268.6
17	9.50	14344.28	1076.00	7.50	1028.00	95.54	272.6
18	7.17	2262.76	112.00	4.95	90.00	80.36	*
19	7.17	2222.35	102.00	4.59	81.00	79.41	*
20	9.50	18371.45	1389.00	7.56	1331.00	95.82	269.6
21	9.50	16997.62	1271.00	7.48	1216.00	95.67	286.8
22	9.50	18357.97	1373.00	7.48	1316.00	95.85	272.0
23	9.50	16580.10	1183.00	7.14	1131.00	95.60	265.8
24	9.33	16755.20	1244.00	7.42	1186.00	95.34	273.7
25	9.17	16741.73	1214.00	7.25	1164.00	95.88	268.0
26	9.17	15691.14	1129.00	7.20	1081.00	95.75	*
27	8.33	10990.55	825.00	7.51	787.00	95.39	*
28	6.83	5481.79	353.00	6.44	329.00	93.20	*
29	9.17	13253.31	952.00	7.18	899.00	94.43	268.5
30	9.17	16809.05	1238.00	7.37	1187.00	95.88	271.2
	215.67	349003.56	23185.00	6.64	22091.00	95.28	286.8

Table V.—Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of December, 1984.

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	9.17	12458.65	921.00	7.39	876.00	95.11	268.6
2	9.17	10249.76	720.00	7.02	678.00	94.17	*
3	5.50	4633.27	268.00	5.78	243.00	90.67	*
4	9.00	11313.79	817.00	7.22	775.00	94.86	273.2
5	7.17	3501.88	203.00	5.80	180.00	88.67	*
6	8.83	9441.63	637.00	6.75	597.00	93.72	*
7	9.17	15691.14	1158.00	7.38	1102.00	95.16	265.4
8	9.17	15516.05	1113.00	7.17	1062.00	95.42	264.8
9	8.67	15745.02	1139.00	7.23	1091.00	95.79	*
10	6.67	6896.03	473.00	6.86	444.00	93.87	*
11	7.83	5091.22	306.00	6.01	280.00	91.50	*
12	8.50	8027.41	541.00	6.74	505.00	93.35	*
13	8.17	11300.32	793.00	7.02	758.00	95.59	*
14	6.83	7434.78	495.00	6.66	467.00	94.34	*
15	7.67	7973.53	515.00	6.46	487.00	94.56	*
16	4.83	1629.72	50.00	3.07	36.00	72.00	*
17	8.00	12566.38	860.00	6.84	825.00	95.93	*
18	8.00	9576.31	648.00	6.77	616.00	95.06	*
19	6.33	3313.32	184.00	5.55	164.00	89.13	*
20	8.00	4835.30	306.00	6.33	277.00	90.52	*
21	2.00	1117.91	20.00	1.79	14.00	70.00	*
22	8.33	9522.45	650.00	6.83	616.00	94.77	260.4
23	8.67	16122.15	1154.00	7.16	1102.00	95.49	261.1
24	8.17	8539.22	578.00	6.77	543.00	93.94	*
25	8.83	16593.58	1213.00	7.31	1160.00	95.63	257.1
26	9.00	15798.91	1145.00	7.25	1095.00	95.63	262.2
27	8.33	7407.84	517.00	6.98	481.00	93.04	*
28	8.00	8269.83	557.00	6.74	523.00	93.90	*
29	9.00	15920.12	1107.00	6.95	1065.00	96.21	*
30	5.83	3084.34	170.00	5.51	151.00	88.82	*
31	5.33	1750.95	64.00	3.66	49.00	76.56	*
	238.17	281322.82	19322.00	6.87	18262.00	94.51	273.2

Table VI.—Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of January, 1985.

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	6.67	3111.29	155.00	4.98	136.00	87.74	*
2	4.67	1360.35	38.00	2.79	22.00	57.89	*
3	5.17	1521.97	51.00	3.35	35.00	68.63	*
4	4.17	1481.57	36.00	2.43	24.00	66.67	*
5	8.17	11717.86	933.00	7.96	888.00	95.18	255.5
6	9.00	16351.13	1186.00	7.25	1135.00	95.70	264.0
7	8.00	8700.84	604.00	6.94	569.00	94.21	*
8	8.67	12000.69	867.00	7.22	824.00	95.04	255.2
9	9.17	18102.06	1325.00	7.32	1263.00	95.32	255.7
10	3.50	2814.98	94.00	3.34	80.00	85.11	*
11	2.33	6236.04	92.00	1.48	66.00	71.74	*
12	0.00	16149.09	0.00	0.00	0.00	*	*
13	0.00	10815.46	0.00	0.00	0.00	*	*
14	9.17	17293.95	1235.00	7.14	1177.00	95.30	259.1
15	9.17	18290.62	1328.00	7.26	1267.00	95.41	257.4
16	8.67	17590.25	1272.00	7.23	1213.00	95.36	257.5
17	0.00	3124.76	0.00	0.00	0.00	*	*
18	1.67	2666.82	44.00	1.65	23.00	52.27	*
19	7.33	8323.71	544.00	6.54	510.00	93.75	249.2
20	6.83	12229.67	782.00	6.39	736.00	94.12	210.2
21	1.17	17347.80	26.00	0.15	19.00	73.08	*
22	8.33	16499.28	1162.00	7.04	1108.00	95.35	267.5
23	9.50	18762.04	1389.00	7.40	1325.00	95.39	263.4
24	8.67	7192.33	497.00	6.91	462.00	92.96	*
25	7.17	7784.97	543.00	6.97	510.00	93.92	254.7
26	1.17	18182.88	44.00	0.24	34.00	77.27	*
27	0.00	6262.99	0.00	0.00	0.00	*	*
28	3.83	9616.72	175.00	1.82	153.00	87.43	*
29	9.50	18896.72	1236.00	6.54	1170.00	94.66	259.1
30	8.83	14249.99	1032.00	7.24	985.00	95.45	257.3
31	0.00	1185.25	0.00	0.00	0.00	*	*
	170.50	325864.08	16690.00	5.12	15734.00	94.27	267.5

Table VII.—Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of February, 1985.

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	5.17	1737.47	61.00	3.51	44.00	72.13	*
2	6.17	1885.63	71.00	3.77	53.00	74.65	*
3	9.83	17293.95	1266.00	7.32	1206.00	95.26	261.9
4	9.67	16970.70	1286.00	7.58	1222.00	95.02	262.6
5	7.50	2639.89	125.00	4.74	106.00	84.80	*
6	8.50	8229.45	564.00	6.85	529.00	93.79	*
7	9.83	18829.40	1387.00	7.37	1323.00	95.39	254.5
8	9.67	20741.95	1459.00	7.03	1387.00	95.07	245.8
9	1.00	20809.30	28.00	0.13	22.00	78.57	*
10	0.00	20607.27	0.00	0.00	0.00	*	*
11	0.00	14465.49	0.00	0.00	0.00	*	*
12	0.00	2464.79	0.00	0.00	0.00	*	*
13	0.00	11960.31	0.00	0.00	0.00	*	*
14	3.50	13334.11	242.00	1.81	212.00	87.60	257.0
15	9.50	18883.25	1248.00	6.61	1184.00	94.87	264.5
16	10.00	18869.78	1420.00	7.53	1360.00	95.77	264.3
17	9.17	7865.79	533.00	6.78	498.00	93.43	*
18	10.50	20526.44	1528.00	7.44	1467.00	96.01	267.8
19	10.00	14290.40	1041.00	7.28	997.00	95.77	258.3
20	10.33	20203.20	1527.00	7.56	1468.00	96.14	269.1
21	10.33	17671.07	1301.00	7.36	1247.00	95.85	264.7
22	9.67	12418.23	871.00	7.01	833.00	95.64	*
23	10.00	17334.36	1269.00	7.32	1224.00	96.45	268.7
24	10.17	17980.85	1309.00	7.28	1266.00	96.72	268.4
25	9.67	11704.39	837.00	7.15	803.00	95.94	*
26	8.33	4431.23	262.00	5.91	238.00	90.84	*
27	10.33	18357.97	1389.00	7.57	1340.00	96.47	265.7
28	10.67	21738.65	1635.00	7.52	1570.00	96.02	268.6
	209.50	394245.33	22659.00	5.75	21599.00	95.32	269.1

Table VIII.—Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of March, 1985.

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	10.00	15340.95	1134.00	7.39	1086.00	95.77	264.7
2	10.67	19879.95	1469.00	7.39	1413.00	96.19	263.4
3	10.83	21307.64	1586.00	7.44	1524.00	96.09	286.8
4	3.67	1481.57	23.00	1.55	12.00	52.17	*
5	10.50	22546.76	1691.00	7.50	1635.00	96.69	268.8
6	11.00	23449.19	1778.00	7.58	1708.00	96.06	263.5
7	10.67	13334.11	970.00	7.27	921.00	94.95	*
8	8.17	2680.29	134.00	5.00	111.00	82.84	*
9	10.67	22546.76	1682.00	7.46	1621.00	96.37	263.7
10	11.00	22802.68	1701.00	7.46	1642.00	96.53	265.8
11	9.67	6424.61	417.00	6.49	385.00	92.33	*
12	8.67	14573.23	1063.00	7.29	1021.00	96.05	262.3
13	10.17	18048.20	1333.00	7.39	1280.00	96.02	266.8
14	9.50	14196.10	1046.00	7.37	1002.00	95.79	262.2
15	11.00	23274.10	1759.00	7.56	1695.00	96.36	259.7
16	11.17	21334.58	1573.00	7.37	1514.00	96.25	276.1
17	11.00	19893.43	1506.00	7.57	1442.00	95.75	267.8
18	11.17	23637.76	1791.00	7.58	1721.00	96.09	255.7
19	11.17	22573.70	1683.00	7.46	1616.00	96.02	264.6
20	11.17	10734.63	724.00	6.74	685.00	94.61	*
21	10.83	14236.51	1023.00	7.19	973.00	95.11	*
22	9.17	3461.47	191.00	5.52	165.00	86.39	*
23	8.33	2559.07	121.00	4.73	98.00	80.99	*
24	7.67	2680.29	125.00	4.66	104.00	83.20	*
25	10.83	16620.49	1213.00	7.30	1160.00	95.63	261.7
26	11.50	23961.00	1757.00	7.33	1688.00	96.07	261.3
27	11.67	22250.46	1587.00	7.13	1531.00	96.47	261.4
28	11.33	20149.31	1425.00	7.07	1379.00	96.77	263.3
29	10.17	6909.50	434.00	6.28	406.00	93.55	*
30	10.00	3905.95	211.00	5.40	183.00	86.73	*
31	7.67	2612.95	113.00	4.32	92.00	81.42	*
	311.00	459407.25	33263.00	7.24	31813.00	95.64	286.8

conversion unit was converting the DC energy from the array into usable AC energy, with a monthly total at the bottom. The third column shows the total solar energy incident on the solar collection area of the array. It does not include the solar energy hitting the support structures. This column represents the total daily kilowatt-hours of solar energy including the energy incident on the array when the photovoltaic system is not up. So this number is the total solar energy available to the system for conversion. A monthly total is at the bottom. The fourth column is the arrary energy in kilowatt-hours. This is the DC energy converted by the solar modules for the entire day and represents the input energy to the power conversion unit inverter. The fifth column is the array efficiency. It is the ratio of the DC energy of the array to the total solar energy available to the system with the monthly total at the bottom. The sixth column is probably the most important column. It shows the total daily power conversion unit output AC energy in kilowatt-hours. This is the energy that directly offsets the energy requirements of the Intercultural Center. The seventh column shows the power conversion unit efficiency as a ratio of the power conversion unit output energy to the array input energy. The last column shows the peak power in kilowatts at normal operating cell temperature of 28°C. It is based on a series of measurements taken during array acceptance tests performed on August 22, 1984. During this acceptance test, a number of conditions had to be satisfied before a data point was accepted. The array had to be clear of shadows, the solar energy had to be stable and above 600 watts per square meter, and the cell temperatures had to be stable for three minutes. The data collected included the cell temperatures, instantaneous array current and voltage, solar incident insolation, and array short circuit current. In order to correlate the data with that taken during the acceptance test, a software program in the ON-SITE DATA ACQUISITION SYSTEM COMPUTER decides every ten minutes that the system is up whether conditions are the same as they were during the acceptance test. The number in the last column represents the peak daily value for the peak power at normal operating cell temperature. It is the highest value recorded at any time during the day. If at no time during the day were all of the required conditions met, than an asterisk is placed in the column. The number at the bottom of the column represents the peak value recorded in the month.

Conclusions

The photovoltaic higher education national exemplar facility at Georgetown University is operating successfully. The data show that the array efficiency to date has not achieved the design efficiency of 10% but is increasing as the sun rises higher in the sky. The peak power at normal cell operating temperature has not achieved the design goal of 300 KW but it also is increasing monthly. The estimated peak load demand of the Intercultural Center is 600 KW so the photovoltaic array, at best, can supply 50% of the peak power loads.

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Pressure Distribution Around a Well Producing at Constant Pressure in a Double-Porosity Reservoir

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ABSTRACT

This paper presents the characteristics of the pressure response of observation wells during a constant pressure test in a double-porosity bounded system. Wellbore skin in the constant pressure active well is considered negligible. The interacting effects of the exterior radius, r_{eD}, and the interporosity flow parameter, λ, are examined in pressure-radius and pressure-time responses. The pressure-radius semilog responses are semilog straight in the region around the well, indicating a constant rate in space. The shape of the fracture interference pressure response of the observation well is similar to the pressure response during constant rate tests in double-porosity systems. The dimensionless pressure response has a transition period where, for the pseudo steady state interporosity flow model, the pressure is constant. Interference fracture pressure responses for the pseudo steady state and the transient interporosity flow models are compared.

Introduction

The model for a well producing at a constant pressure is used for decline curve analysis. The mathematical solution for the rate decline of a single-porosity system was presented by *Carslaw and Jaeger* [1960] and *Van Everdingen and Hurst* [1949]. The interference pressure response to a constant pressure test was considered by *Uraiet and Raghavan* [1980], again in a single porosity-reservoir. They presented log-log type curves for various interference wells in an infinite reservoir.

In naturally fractured reservoirs, fluid flows both in the fractures and in the matrix blocks. *Barenblatt and Zeltov* [1960] and *Warren and Root* [1963] presented a mathematical model for double-porosity systems with pseudo steady state (PSS) matrix behavior. *Da Prat et al.* [1981] and *Raghavan and Ohaeri* [1980] considered the rate decline of a well producing at constant pressure in a bounded double-porosity system. *Da Prat et al.* [1981] presented the Laplace solution for the rate decline of a well including wellbore skin, but presented type curves only for zero skin. Also, they did not present a single log-log type curve for various combinations of the three parameters that were considered, r_{eD}, ω, and λ.

Sageev et al. [1985] presented a decline curve analysis method that extends the method presented by *Fetkovich* [1980] to double-po-

rosity systems. They presented a single log-log type curve that describes the rate decline behavior as a function of four parameters: r_{eD}, S, ω, and λ. They used the PSS interporosity flow model for developing the type curve, but also considered the relation between the PSS and the transient interporosity flow model with fractured skin. The double-porosity model that includes transient matrix flow with fracture skin was presented by *Moench* [1983] and *Moench* [1984].

In this paper, we examine the pressure distribution around a well producing at a constant pressure, without wellbore skin, in a bounded double-porosity reservoir. Both pressure-radius profiles at fixed times, and pressure-time responses at fixed locations are presented. The effects of λ and r_{eD} on interference pressure responses are considered, as well as the practical aspects of interference constant pressure testing in double-porosity systems.

Theory

The following presents a short description of the mathematical solution for a well producing at constant pressure in a double-porosity bounded reservoir. Reservoir and fluid properties are considered homogeneous, and gravity and inertial effects are neglected. *Deruyck et al.* [1982] presented the fracture diffusivity equation:

$$\frac{k_f}{\mu}\nabla^2 p_f = (\phi\mu c_t)_f \frac{\partial p_f}{\partial t} - q^* \qquad (1)$$

where q^* is the rate of flow between the matrix and the fractures. The initial and boundary conditions associated with the fracture diffusivity equations are:

$$p_f(r,0) = p_i \qquad (2)$$

$$p_f(r_w,t) = p_{wf} \qquad (3)$$

$$\left(\frac{\partial p_f}{\partial r}\right)_{r_e} = 0 \qquad (4)$$

Making use of the initial condition, the Laplace transformation of the dimensionless form of equation (1) is, *Deruyck et al.* [1982]:

$$\frac{d^2\bar{p}_{fD}}{dr_D^2} + \frac{1}{r_D}\frac{d\bar{p}_{fD}}{dr_D} - sf(s)\bar{p}_{fD} = 0 \qquad (5)$$

where $\bar{p}_{fD}(r_D,s)$ is the Laplace transformations of $p_{fD}(r_D,t_D)$. The dimensionless groups are defined as:

$$p_{fD} = \frac{p_i - p_f}{p_i - p_{wf}} \qquad (6)$$

$$q_D = \frac{qB\mu}{2\pi k_f h(p_i - p_{wf})} \qquad (7)$$

$$t_D = \frac{k_f t}{[(\phi V c_t)_f + (\phi V c_t)_m]\,\mu r_w^2} \qquad (8)$$

$$r_D = \frac{r}{r_w} \qquad (9)$$

The variable $f(s)$ depends on the assumed interporosity flow model. For the pseudo steady state model:

$$f(s) = \frac{\omega(1-\omega)s + \lambda}{(1-\omega)s + \lambda} \qquad (10)$$

For the transient interporosity flow model with slab-shaped matrix, $f(s)$ is:

$$f(s) = \omega + \frac{\lambda}{3s}\, a \tanh(a) \qquad (11)$$

where: $a = \sqrt{\dfrac{3(1-\omega)s}{\lambda}}$

For the transient interporosity flow model with spherically-shaped matrix, $f(s)$ is:

$$f(s) = \omega + \frac{\lambda}{5s}\, b \coth(b) \qquad (12)$$

where: $b = \sqrt{\dfrac{15(1-\omega)s}{\lambda}}$

The parameters ω and λ are defined as:

$$\omega = \frac{(\Phi Vc)_f}{(\Phi Vc)_f + (\Phi Vc)_m} \qquad (13)$$

$$\lambda = \alpha \frac{k_m}{k_f} r_w^2 \tag{14}$$

and the other terms are defined in the Nomenclature.

The pressure solution for observation points away from the constant pressure active well in a bounded reservoir is:

$$\bar{p}_{fD} = \frac{I_1(r_{eD}g)K_0(r_Dg) + K_1(r_{eD}g)I_0(r_Dg)}{s\,[K_1(r_{eD}g)I_0(g) + I_1(r_{eD}g)K_0(g)]} \tag{15}$$

where $g = \sqrt{sf(s)}$.

For an infinite system, the interference pressure solution is:

$$\bar{p}_{fD} = \frac{K_0(r_D\sqrt{sf(s)})}{sK_0(\sqrt{sf(s)})} \tag{16}$$

The matrix pressure for the PSS interporosity flow model is related to the fracture pressure by *Deruyck et al.* (1982):

$$\bar{p}_{mD} = \bar{p}_{fD}\left(\frac{\lambda}{(1-\omega)s+\lambda}\right) \tag{17}$$

Pressure Distribution

As discussed by *Sageev et al.* [1985], the dimensionless rate response of a double-porosity bounded system depends on the values of r_{eD}, ω, and λ. All the presented curves are evaluated using a numerical inversion method of the Laplace transformation developed by *Stehfest* [1970]. The dimensionless rate response of a double-porosity bounded reservoir is presented in Figure 1. The thin curve in the middle represents the response of an infinite homogeneous system. There are two curves for double-porosity bounded systems with a fixed value of the storage coefficient, $\omega = 0.01$, and a fixed value of the dimensionless radius, $r_{eD} = 10^4$. In the uppermost curve, the value of λ is relatively large (10^{-4}), and the double-porosity effects take place prior to the effects of the exterior no-flow boundary. Hence, the rate response is infinite acting at early time controlled by the fractured system, then flattens out for about two log cycles when the rate is almost constant, to be followed by an exponential rate decline of the combined fracture-matrix system.

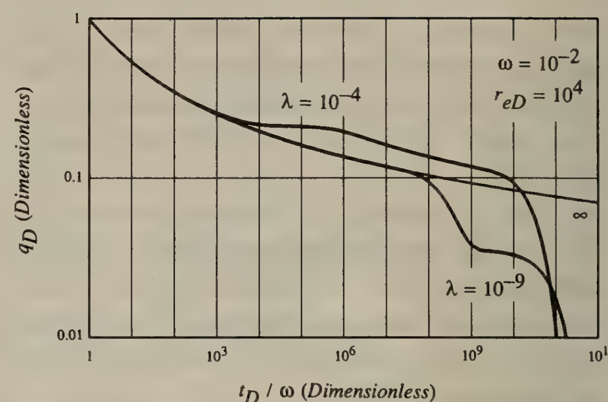

Fig. 1: A typical response of an infinite and finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-4}$, 10^{-9}, and $r_{eD} = 10^4$.

In the lowermost curve in Figure 1 the value of λ is small (10^{-9}), and the effects of the no-flow exterior boundary take place prior to the double-porosity effects. In this case, the infinite acting flow period is followed by an exponential decline of the rate, controlled by the fractured portion of the reservoir. The first exponential decline is followed by the double-porosity effects, yielding almost a constant wellbore rate, as the matrix pressure approaches the fracture pressure. After the flattening flow period, the rate declines exponentially, representing the depletion of the combined fracture-matrix system.

Figure 2 presents the dimensionless rate decline curve when the double-porosity effects take place before the effect of the ex-

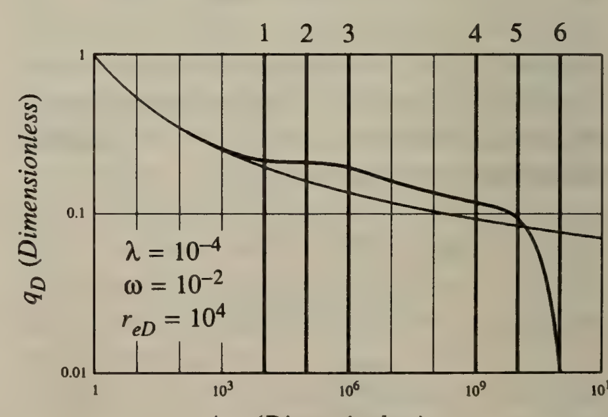

Fig. 2: Log-log response for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-4}$, and $r_{eD} = 10^4$.

terior boundary. Also, six dimensionless times are marked on Figure 2, denoted by 1 through 6. Dimensionless pressure profiles for both the matrix and the fractures are presented in Figure 3. The first profile, for $t_D/\omega = 10^4$ represents the end of the infinite acting flow period of the fractured system. Hence, the matrix dimensionless pressure is negligible, and the fracture dimensionless pressure is negligible at the boundary, $r_{eD} = 10^4$. The pressure profiles marked 2 and 3 represent the intermediate flow period, when the fluid flow from the matrix supports a constant wellbore rate. During this flow period the matrix is depleting, as suggested by curves 2 and 3, yet, the fracture pressure is almost constant as a result of the flow from the matrix to the fracture. The fourth pressure profile represents the end of the infinite acting flow period of the combined matrix-fracture system. Hence, the pressure in the matrix is slightly higher than the fracture pressure, but cannot be distinguished in the figure. The fifth and sixth profiles denote the exponential depletion of the combined matrix-fracture system, as the pressure profiles approach the value of 1.

Figure 4 presents the dimensionless rate decline curve when the effects of the exterior boundary take place prior to the double-porosity effects. The same six dimensionless times as in Figure 2 are marked on Figure 4, denoted by 1 through 6. The pressure profiles for the dimensionless rate response described

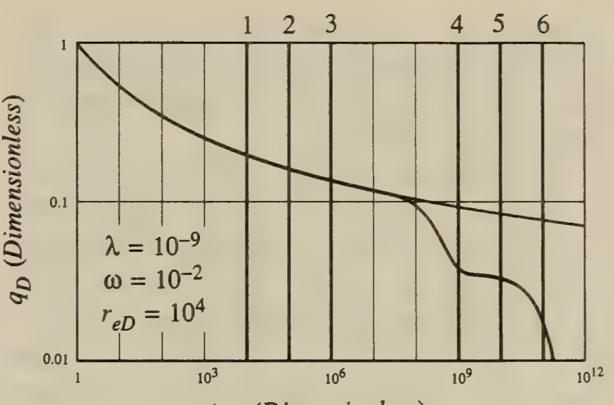

Fig. 4: Log-log response for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-9}$, and $r_{eD} = 10^4$.

in Figure 4 are presented in Figure 5. The first three pressure profiles describe the infinite acting flow period of the fractured system. The fracture pressure is declining throughout the reservoir, while the matrix pressure is constant at the initial pressure, $p_D = 0$. The fourth pressure profile describes the exponential decline of the fractured system caused by the presence of the no-flow exterior boundary. The fifth profile represents the double-porosity effects, resulting in a flattening of the wellbore rate, see Figure 4. The pressure depletion of the matrix is noticeable, while the fracture pressure is almost constant, indicated by the slow upward movement of the pressure profiles. The sixth pressure profile represents the end of the transition flow period when the rate response changes from being dominated by the fractured system, to

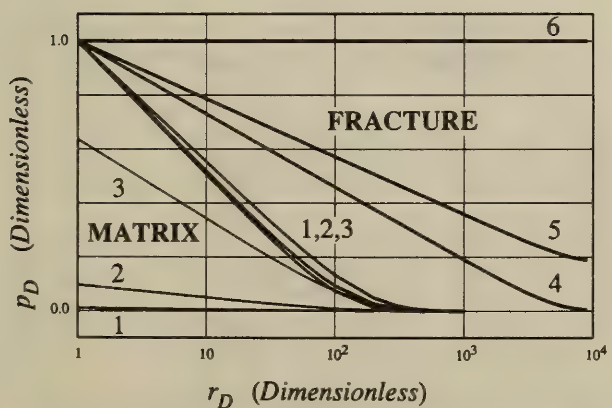

Fig. 3: Dimensionless pressure profiles for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-4}$, and $r_{eD} = 10^4$.

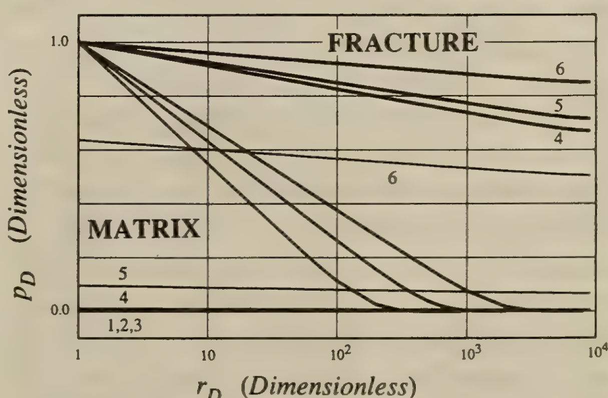

Fig. 5: Dimensionless pressure profiles for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-9}$, and $r_{eD} = 10^4$.

the combined matrix-fracture system. The matrix pressure approaches the fracture pressure and eventually, the complete reservoir depletes exponentially.

The Semi-log pressure profiles presented in Figures 3 and 5 are straight lines in the region surrounding the wellbore. This indicates a constant rate in space. The slope of the semi-log pressure profiles is proportional to the fracture flow rate that decreases with time. The constant rate flow period at the well is accompanied by a period when the slope of the pressure profiles is almost constant.

Interference Responses

In this section we examine the pressure-time responses at various locations away from the active constant pressure well. The double-porosity effects and the exterior boundary effects on interference pressure responses are examined for the PSS interporosity flow model, followed by a short discussion of transient interporosity flow models. We assume that wellbore storage is negligible at interference wells.

Interference pressure responses when the double-porosity effects take place prior to the effects of the exterior boundary are presented in Figure 6. Four dimensionless radii are considered for a fixed value of the dimensionless exterior radius, $r_{eD} = 10^4$. The thick family of curves represents the dimensionless pressure response of the fractures and the other family of curves represents the dimensionless pressure response of the matrix blocks. The interference response of the fractures increases initially, in this case up to $t_D/\omega = 10^4$. Then, the dimensionless pressure becomes practically constant for about two log cycles. The length of the constant pressure period is proportional to the log of $1/\omega$. After $t_D/\omega = 5*10^5$, the pressure response of the combined matrix-fracture system increases, and is infinite acting up to $t_D/\omega = 10^{10}$ (as can also be seen in Figure 1). At $t_D/\omega = 10^{10}$ the system depletes exponentially, and the dimensionless pressure approaches the value of 1.

The matrix pressure response is smoother than the fracture pressure response. The matrix and fracture pressure responses join to a single curve at $t_D/\omega = 5*10^6$ for this case, indicating a combined depletion of the total system. The constant pressure period of the interference fracture pressure response is significant. This is similar to the dimensionless pressure response of a well producing at a constant rate, as presented by *Deruyck et al.* [1982]. The flattening of the pressure response is indicative of double-porosity behavior of fissured systems. The derivative of the interference pressure response has a double hump that is similar to the pressure derivative presented by *Bourdet et al.* [1984].

Interference pressure responses when the exterior boundary effects occur prior to the double-porosity effects are presented in Figure 7. In this case, the system behaves like a single porosity system up to $t_D/\omega = 5*10^7$. This is a much longer time in comparison to the case when the double-porosity effects take place prior to the boundary effects, that was at $t_D/\omega = 10^4$. The matrix pressures for the various dimensionless radii are practically the same, as indicated in Figure 7, and can be seen in the fifth and sixth matrix pressure responses in Figure 5. Figure 8 presents the responses of the same system described in Figure 7, except that $1 - p_D$ is used instead of p_D. Here, the constant pressure period is present, but occurs late into the test, starting at $t_D/\omega = 10^9$. Also, the difference between the responses at various radii is much smaller

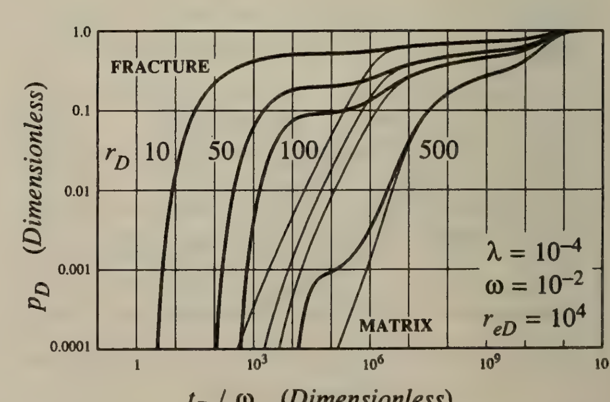

Fig. 6: Interference responses for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-4}$, $r_D = 10,50,100,500$, and $r_{eD} = 10^4$.

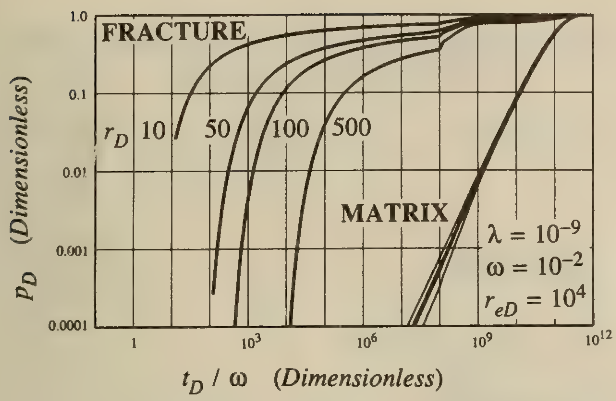

Fig. 7: Interference responses for a finite double-porosity system, PSS model, $\omega = 0.01$, $\lambda = 10^{-9}$, $r_D = 10, 50, 100, 500$, and $r_{eD} = 10^4$.

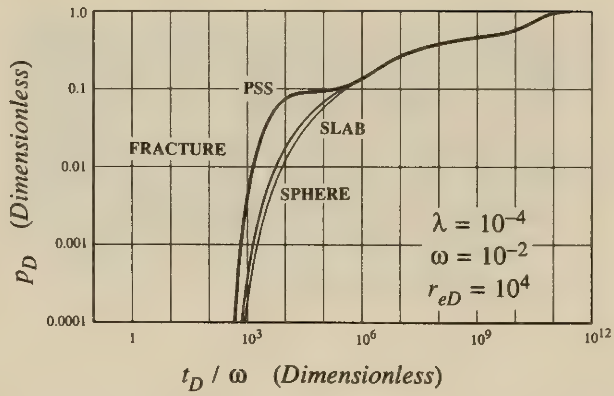

Fig. 9: A comparison between interference fracture pressure response for PSS and transient interporosity flow models. $\omega = 0.01$, $\lambda = 10^{-4}$, $r_D = 100$, and $r_{eD} = 10^4$.

in comparison to the responses described in Figure 6. When $t_D/\omega > 10^{11}$, the dimensionless rate of the combined matrix-fracture system declines exponentially, and $1 - p_D$ approaches 0.

Interference fracture responses for the PSS and transient interporosity flow models are presented in Figure 9. Here, the double-porosity effects take place prior to the boundary effects, $r_{eD} = 10^4$, $r_D = 100$, $\omega = 0.01$, and $\lambda = 10^{-4}$. Slab and spherically shaped matrix blocks for the transient flow model are considered. The introduction of transient matrix flow reduces the pressure differences between the matrix and the fractures, and reduces flattening of the pressure response. In the responses presented in Figure 9, the PSS flow model has a significant constant pressure period, and the two transient flow models do not. The three fracture responses converge to

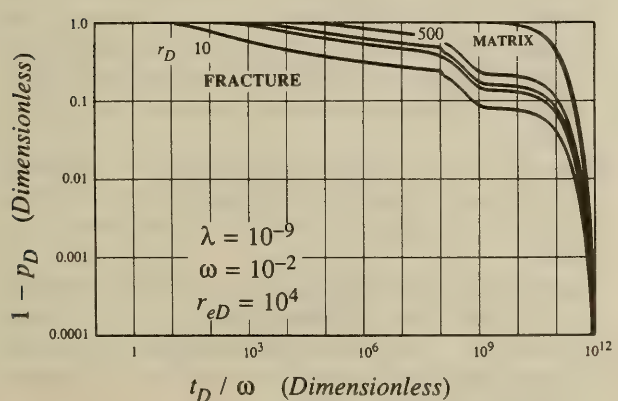

Fig. 8: Interference responses for a finite double-porosity system, PSS model, using $1 - p_D$ instead of p_D. $\omega = 0.01$, $\lambda = 10^{-9}$, $r_D = 10,50,100,500$, and $r_{eD} = 10^4$.

a single curve at $t_D/\omega = 5 * 10^5$, that is one log cycle earlier than when the PSS matrix pressure converges to the fracture response, see Figure 6. *Sageev et al.* [1985] showed that transient matrix blocks with fracture skin greater than ⅓ yield a response similar to the PSS interporosity flow model.

Conclusions

1. The fracture pressure profiles in the region around the active constant pressure well are semi-log straight, indicating constant rate in space.
2. The slope of the fracture pressure profiles is nearly constant during the constant rate flow period at the active well.
3. The fracture pressure response at observation wells has a constant pressure period (PSS interporosity flow model) similar to the constant rate tests.
4. For a double-porosity reservoir with a small value of the interporosity flow parameter, λ, the double-porosity effects occur late into the test, and may be detected only if $(1 - p_D)$ is used instead of p_D.
5. The magnitude of the interference pressure drops at observation wells increases as the distance between the observation well and the active well decreases.
6. For a given reservoir, the interference matrix pressure converges to the interference fracture pressure at the same time, and the double-porosity effects occur at the same time for all interference locations.

7. Transient interporosity matrix flow reduces the pressure difference between the matrix and the fractures, and reduces the flattening of the interference pressure response. The fracture interference pressure responses for double-porosity reservoirs with slab shaped or spherically shaped matrix blocks are similar.

Acknowledgement

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Nomenclature

B = formation volume factor
I_0 = modified Bessel function, first kind, zero order
I_1 = modified Bessel function, first kind, first order
K_0 = modified Bessel function, second kind, zero order
K_1 = modified Bessel function, second kind, first order
V = ratio of volume of one porous system to bulk volume
c = compressibility
h = formation thickness
k = permeability
p = pressure
p_D = dimensionless pressure
$\overline{p}_D$ = Laplace transform of p_D
q = volumetric rate
q_D = dimensionless rate
$\overline{q}_D$ = Laplace transform of q_D
q^* = matrix flow rate
r = radius
s = Laplace variable
t = time
t_D = dimensionless time
λ = interporosity flow coefficient
μ = viscosity
ϕ = porosity
ω = dimensionless fracture storage
α = interporosity shape factor

Subscripts

D = dimensionless
f = fracture
m = matrix
t = total
w = wellbore
e = exterior

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"On Science as a Liberal Art"

Raymond J. Seeger, NSF (ret.)

The Editors are to be congratulated upon the inauguration of symposia on contemporary issues such as D.C. undergraduate education in the March 1985 Journal. Deans from four representative Washington colleges were invited to speculate on its future as they see it: one is Roman Catholic, another Protestant related, the third now secular, the fourth largely federally funded. As a former teacher at two of these institutions, I found the personal views expressed quite interesting.

I was, however, somewhat chagrined to find comparatively little concern as to the general function of a college and as to how a department or course was related to it. There was a tendency to speak glibly even about liberal arts without bothering to define this ambiguous term. Originally the seven liberal arts included the trivium (grammar, logic, rhetoric) and the quadrivium (arithmetic, geometry, music (i.e., applied mathematics), astronomy (the science of that time)). Although a physics major, I received a B.A. degree from my liberal arts college, which required Latin or Greek for it (I was the only member of my class who had both). Nowadays even a B.S. does not necessarily signify a major in any science. One Dean did list the modern liberal arts: "literature and history, language and the sciences, philosophy and theology and the fine arts like drawing and music." (Note that mathematics per se is not included, language is singular, but sciences are plural.) Some years ago some Phi Beta Kappa material used the phrase "the liberal arts and sciences." I inquired if that implied that science is not a liberal art. I was assured the phrase intended to emphasize that it is. I did not counter with the observation that "boys and girls" does not usually mean that girls are really boys. Today colleges frequently shorten the phrase to arts and sciences, resulting in an even more nebulous phrase. I still appreciate the traditional approach of the French philosopher Jacques Maritain, who can not be accused of being a science: "Physics should be taught and revered as a liberal art of the first rank like poetry" (my English colleagues never agreed).

It is noteworthy, but accidental, that none of the Deans happens to be a scientist. Often a dean loses his own scholarly interests upon becoming an administrator; he may actually become anonymous. In one instance I had to ask seven persons, including faculty, in the dean's office before I could ascertain his field. The deans here represent history (two), literature (Polish), and jurisprudence. It would be interesting to know their own scientific backgrounds, particularly in view of their apparent general lack of understanding or even appreciation of science per se.

As sometime chairman of a curriculum committee, I agree that the faculty as a whole should periodically review all courses in the light of changing goals and developments, as well as their relations to one another. I, too, deplore the administrative fights that have to be settled continually about territorial domains and tenure rights. Nevertheless, no mention is made of the losses suffered by students whose education is made to depend upon the financial success of each course offering. I am personally in favor of a professor offering only what he himself understands and enjoys. Much is made by some Deans about research-and-education. In general, the maximum is achieved only when these two are related—not research on this, but teaching that. Moreover, there are cases where good teachers have been poor researchers—and visa versa. A teacher will be a better teacher gen-

erally only if he is teaching about his own research!

What is truly disappointing is the failure of the group as a whole to appreciate a good lecture, particularly a scientific lecture with phenomenal demonstrations (not just slides or movies). Derogatory remarks about lectures are common: "poorly presented," "ill presented", "musty lecture notes" (I myself used the same lecture notes each year—continually improved). There seems to be a common assumption that a lecture is merely a poor reading of printed material. On the contrary, to give a good lecture requires "the same dedication that an actor has to a new role" (the audience is always new). There is the organization, the emphasis, the enthusiasm! Good lectures are good; they may even inspire and be long remembered!

The easiest way to conduct a class is to let it conduct itself, often haphazardly, leading nowhere. It takes an exceptional leader to guide stray thoughts towards a reasonable conclusion. A good discussion chairman is as rare as a good lecturer! I certainly cannot help feeling sorry for the Dean who would rather have no book at all than Milton on a desert island. Such lack of appreciation is due initially to his first teacher, but now is his own responsibility. How often students are deprived of their rightful heritage by poor teachers who crowd the gateway inscribed, "Abandon all hope, you who enter it." One wonders, too, about the unfortunate experience of the Dean who sees in great books "only a legacy (mostly) by dead white males." The health, race, and sex of authors is hardly a criterion for judging the value of their works.

What discouraged me most of all was the lack of attention given by the Deans—not to science—but rather to the universe per se. One factor that changes my own college major from the classics to physics (academically my poorest subject) was the intellectual challenge of this mysterious universe. Yet no one mentioned that in addition to the 3 R's there is an increasing need today to learn to observe phenomena—not to mention the fourth R religion. The science laboratory lies hidden behind closed doors. And yet, it is here that the student is brought into direct contact with natural phenomena in an understanding way. The closest remark, "if you want to know how things work, satellites, fiber optics, space shuttle, the telephone system, take physics" is obviously technology—not science. It might motivate an engineer, but not necessarily a theoretical physicist (I am notorious as a repairman about the house). The most important ingredient for science, as well as for literature and art, is never even mentioned, i.e., imagination. Einstein was once asked what a child should read. He replied, "Fairy tales!" "What then?" the mother persisted. "More fairy tales!" "and then?" she said hopefully. "Still more!" What is lacking in the Deans' concerns is the cultivation of insight, of spiritual points of view, of visions that lift up and uplift!

There is one emphasis of the Deans that I strongly endorse, viz, the desirability of an interdisciplinary outlook, which should be developed increasingly over the years. When I was teaching an introductory course in physical science, I invited a professor of history to discuss its relation to science. "History," he explained, "is the study of man and his environment." Later a professor of philosophy claimed, "Philosophy is the study of man and his environment." The next year I began the course, "Science is the study of man and his environment!" I had gotten the idea. We all live in one world, the same world—we just look at it from different points of view. Every professor, I believe, should state his position and outline his outlook. He should indicate where his horizon meets other horizons. In their senior year students from different disciplines should meet in a seminar to discuss some common, contemporary issue(s) such as social, ethical, or philosophical (possibly theological) aspects of science—all under interdisciplinary faculty guidance. (Although I invited professors of other disciplines to speak in my classes, they never invited men.)

The Dean's pay some homage to the idea of the unity and integrity of knowledge, but fail to show how this can be realized. What is more, they do not acknowledge the cumulative progress that has actually been made along this line by cooperative science—in contrast with the self-satisfaction of individualistic humanities.

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Biological Control as a Management Strategy in the Great Lakes[1]

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ABSTRACT

Nuisances in Great Lake environments have most often been attacked through the use of chemicals or other unnatural means. Although many of these nuisances are economically undesirable, in order to sustain our natural resources we must develop convergent strategies that do not achieve economic goals at the expense of the environment. With the increased awareness of biotechnology more attention should be paid to developing, adapting, and exploiting characteristics of Great Lake ecosystems that will contribute to the biological control of nuisances. This paper discusses alternatives to present management strategies focusing on the use of natural biological systems to mitigate or eliminate nuisances such as aquatic weeds and sea lamprey, rather than intervening with unnatural solutions after problems reach crisis levels. Discussion emphasizes the control of aquatic weed growth through enhanced grazing by crayfish and the control of sea lamprey parasitism on game fish through predation by Lake Sturgeon. It is hoped this paper will demonstrate that biological controls applied to problems facing Great Lake natural resource managers may show merit and be worth considering. If feasible, these strategies will provide management options that emphasize sustainability of our natural resources.

Introduction

The environment within which we live is an arrangement of independent and yet cooperating systems that in one way or another support much of man's economic growth. To develop a philosophy of sustainability for our natural resources requires the development of convergent strategies that minimize having to choose between environmental and economic alternatives and maximize the achievement of economic and environmental goals in concert. As we have already learned through numerous case histories, over the long-term, deterioration in environmental systems translates to deterioration in economic systems. Therefore, we must reevaluate management policies that emphasize maximum benefit from natural resources at the expense of the environment that supports these natural resources.

Biotechnology includes a collage of different research areas and encompasses a diversity of means for using living matter to develop useful products, including the exploitation of biological processes occurring in

[1]Contribution Number 29, State University of New York Research Center at Oswego.

nature for the benefits of man and the environment. The National Science Foundation defines biotechnology to include the "controlled use of biological agents, such as organisms or cellular components, for beneficial application" (Markle and Robin, 1985) *Biological control*, which is an extension of biotechnology, is largely based upon processes that occur continually in nature. Cotton, one of the most developed insecticide-intensive crops, serves as a good example of the benefits derived from biological control methodology. Cotton hosts more than 25 resistant anthropods, many of which seriously damage crops only after their natural predators have been eradicated by the same chemical controls (Mlot, 1985). Alternative pest control strategies are being developed for this industry in order to prevent (1) genetic selection in the pests leading to eventual resistance to chemicals and (2) harmful effects to other components of the environment that might otherwise aid in control of the pests (*i.e.* death of natural predators). The results of this research into cotton pest control has been the development of Integrated Pest Management (IPM; Frisbie and Adkisson, 1985) where, among other strategies, insect pest populations are monitored to gauge resistance to chemical treatment and beneficial (predator) insects are stimulated to compete with the pests, *i.e.,* biological control.

Through history, there have been other biological control strategies applied to environmental problems. The killifish, *Fundulus heteroclitus*, was examined for its ability to control mosquito populations (in the larval stage) in Long Island, New York (Chidester, 1916). Because of the success of this fish in feeding on larvae of mosquitos and green-head flies, artificial stocking was proposed as a control to the nuisance. Gypsy moths serve as another example of biological controls lessening a pest's impact (Beroza and Knipling, 1972). The use of the species' own sex pheromone served as a means of trapping males of the populations and breaking the reproductive cycle of the pest. Perhaps the most recent example of biological control in the aquatic environment is the manipulation of trophic levels to eliminate or control nuisance populations (pests) in lake ecosystems. Fish and zooplankton populations have been manipulated to biologically control nuisance phytoplankton (Shapiro, 1982; Vanni, 1984; Spencer and King, 1984). Salmonid stocking programs in the Great Lakes were initiated, among other reasons, to biologically control the abundant alewife populations and reduce the nuisance of massive annual die-offs of this species. The cascading effect of this control has been reduced predation on zooplankton by the alewife (Eck and Brown, 1985) and in turn, smaller phytoplankton standing stocks (food of zooplankton), resulting in clearer waters for Lake Michigan (D. Scavia, 1984; D. Scavia, Great Lakes Environmental Research Laboratory, personal communication, 1985).

Disturbances to Great Lake environments, which have impacted man's use of these resources, have most often been attacked through an interventive approach. For example, the accumulation of toxic compounds within the food chain of Lake Ontario resulted in the ban of human consumption of many fish species. Likewise, the offensive growth of aquatic weeds and macroalgae along the lakeshores has been controlled through harvesting or with the use of herbicide chemicals. Another nuisance to Great Lake environments has been the sea lamprey and its parasitic attack on stocked salmonids sought by recreational fisherpersons. This problem has been attacked by use of toxic poisons as an interventive control strategy, at the expense of the habitats in which lamprey spawn. To protect the large investments in fish stocking and create suitable waters for recreational boating, management responses to these and other Great Lake environmental problems have been reactive (interventive), usually through chemical or other unnatural means, rather than preventative, where action is taken before the particular problem reaches a crisis level.

With the advent of biotechnology more attention should be paid to the concept of developing, adapting, and exploiting natural biological characteristics of the Great Lakes to address the ever-growing problems associated with these ecosystems. It is recognized that aquatic systems are quite resilient and capable of tapping their own resources to recover and adapt from perturbations (*e.g.*, Harrison 1979; Deangelis 1980). This recognition suggests

that man work with ecosystem characteristics for the enhancement of natural attributes that will contribute to the biological control of disturbances. Consider, for instance, that crayfish have the potential in lake systems to control aquatic weeds. Is it possible that by promoting crayfish populations need for using chemical or mechanical controls in weed-choked lake embayments could be reduced? It is also known that sea lamprey are used as bait by sturgeon fishermen in midwestern lakes. Sturgeon were all but eliminated in the Great Lakes at about the time the sea lamprey made significant inroads. Is it possible that the benthos-feeding sturgeon could significantly reduce sea lamprey populations before their parasitic stage, thereby reducing the need for chemical controls?

Biological control strategies have proved extremely successful in the management of terrestrial environmental problems (*e.g.* pests). In addition, lessons from terrestrial case histories tell us that continued reliance on chemical control of pests such as aquatic weeds and sea lamprey will ultimately result in genetic selection for resistance against treatment and/or inhibition of natural predator effects. Terrestrial approaches to biological control can serve as a model to begin formulating solutions for freshwater nuisances. We suggest that biological controls are viable strategies for the management of several pressing problems that haunt Great Lake environments. Thoughts on a couple of potential strategies are discussed below.

Aquatic Weed Control

The effects of grazing on aquatic vegetation have been extensively studied. Kajak and Warda (1968) and Paine and Vadas (1969) showed a definite effect of grazing on the productivity of attached benthic flora. Castenholz (1961) compared the diatom cover which developed in ungrazed intertidal areas with that in adjacent areas of controlled grazing by limpets. Cooper (1973) observed reduction in producer standing crops by grazing of a starved herbivore, *Notropis spilopterous*. Grass carp (*Ctenopharyngodon idella*) have been observed to graze heavily on submerged macrophytes and eliminate populations of these plants from sublittoral areas of lakes (Shireman and Maceina, 1981). Herbivory on macrophytes by crayfish in freshwater has also been documented. Intense grazing by a dense population of crayfish (*Astacus astacus*) was responsible for the control of submerged vegetation of ponds in Sweden (Abrahamsson 1966). Dean (1969) found a decrease in aquatic weeds to be related to high crayfish densities. Flint and Goldman (1975) observed that crayfish (*Pacifastacus leniusculus*) reduced the biomass of *Myriophyllum* in the clear waters of Lake Tahoe. Lorman and Magnuson (1978) and Lodge (Univ. Wisconsin, personal communication, 1984) noted that even low densities of the crayfish *Orconectes rusticus* reduced macrophytes. They manipulated the density of this crayfish in four replicated enclosure-exclosure experiments in the littoral zones (1–3 m depths) of three northern Wisconsin lakes. In Trout Lake, natural densities of crayfish reduced macrophyte stem number by about 50% (1 crayfish/m^2), 80% (5/m^2), and 100% (10/m^2). In all experiments, macrophyte species number was also reduced.

Littoral zones are essential for growth and survival of many species and the structural heterogeneity created by macrophytes is one of the reasons they are important lake habitats. Some restoration techniques, focusing on macrophyte removal, destroy littoral zones by the use of herbicides and mechanical harvesting. Other technology involves the use of grass carp (*Ctenopharyngodon idella*) to manage submerged weeds. These grazers are capable of completely eliminating weeds in a relatively short time interval. Structurally complex habitats thus become relatively simple areas. Complete weed removal has been shown to cause problems within the lake ecosystem, such as greater availability of nutrients to support nuisance phytoplankton blooms in the water (Carpenter *et al.*, 1983). Other observations have indicated that submerged macrophyte removal appears to disrupt food web stability by reducing predation on zooplankton, creating a size shift to larger zooplankton, reducing phosphorus recycling and thus affecting phytoplankton production (Loucks, 1985).

Crayfish population manipulations could provide a less harmful and more natural solution to controlling macrophyte growth. They do not completely remove weeds but rather control their densities (Flint and Goldman, 1975) below nuisance levels. Despite widespread crayfish abundance, no examples exist of the use of these grazers to control nuisance macrophytic growths in littoral areas of the Great Lakes. In general, these decapods populate estuary and embayment regions, where shoreline development is usually greatest and man has most consistent contact with the aquatic environment. These are also areas that routinely cause greatest concern as a nuisance to boating and unaesthetic appearance of shallow water weed overgrowth. Historical literature indicates crayfish may serve as a biological control for macrophytic overpopulation. Recently manipulation of higher trophic levels (zooplankton and fish) to control nuisance phytoplankton biologically has been illustrated (Shapiro and Wright, 1984; Spencer and King, 1984). The questions to address for crayfish are: 1) why does crayfish control of excessive macrophyte growth not occur in many regions of the Great Lakes where there are problems, and 2) what manipulations can be considered using crayfish populations as a controlling mechanism to offensive aquatic weed growth?

Sea Lamprey Control

Predation by sea lampreys (*Petromyzon marinus*) has long been recognized as a significant mortality source of fish in the Great Lakes, although historical data do not quantify the actual role of this predation in the decline of native fish stocks (Christie and Kolenosky, 1980; Pearce *et al.*, 1980). Interest in sea lamprey control increased following invasion of the upper Great Lakes in the late 1930's, which was in part responsible for the formation of the Great Lakes Fisheries Commission (GLFC) in 1955. Among other responsibilities, the GLFC developed measures and implemented programs to decrease effects of sea lamprey in the Great Lakes, which by 1958 had resulted in control methods utilizing selective chemical toxicants to destroy lamprey ammocoetes (larvae) in their stream habitat (Smith and Tibbles, 1980). Despite the recognized threat from predation, salmonid restoration in Lake Ontario was initiated in 1968 without lamprey control. Impact assessments later indicated significant effects of sea lamprey predation on adult salmonid populations and stimulated a program which now chemically treats identified lamprey spawning tributaries every 3–5 years. Despite implemented controls, lamprey attacks and mortality on salmonids through 1983 were still considered excessive (Eckert, 1984).

Sawyer (1980) was the first to suggest that there may be other, more natural, means of controlling sea lamprey in the Great Lakes than relying on chemical treatment which impacts more than just the target species. He borrowed the approach of "Integrated Pest Management" for sea lamprey control, which included examining the manipulation of natural ecosystem characteristics to effectively limit lamprey impacts. As described previously, the control of pests to terrestrial crop production has relied upon this approach for years and the successes in these areas suggest biological control of the sea lamprey may ultimately be possible.

Comparative species evaluation for similar population dynamics may suggest alternative management techniques that can be applied to control sea lamprey in the Great Lakes. If the missing mortality factor is the lack of natural enemies, then the manipulation of the ecosystem by introduction and/or enhancement of predators could be the solution. One potential candidate to utilize as a biological control for sea lamprey is the Lake Sturgeon (*Acipenser fulvenscens*). This species is extremely rare in most Great Lake environments and has been since the early 1900's, which correlates with sea lamprey invasion. The life cycle of the sturgeon, which includes spawning in tributaries, overlaps the distribution of sea lamprey ammocoetes during their developmental stages in tributary sediments. In addition, the sturgeon feeds off the benthos where ammocoetes are growing before transition to parasitic phases. Anecdotal information is

available that indicates sea lamprey are used as bait by fishermen for Lake Sturgeon in many western lakes. Biological control, either alone or in concert with chemical treatment, which is not environmentally sound or universally effective by itself, in that it impacts other populations besides lamprey, presents a viable alternative to present sea lamprey management. Alternative strategies deserve investigation and the use of Lake Sturgeon as a biological control warrants consideration.

Discussion

The goal of this presentation has been to stimulate thought concerning the need to begin considering alternative means of solving Great Lake environmental problems in order to preserve these valuable natural resources. Although many management strategies presently applied to solve Great Lake disturbances are somewhat successful with respect to the target problem, many of these strategies are reactive and stop-gap in nature. In addition, these solutions often do not address the overall sustainability of the ecosystem. Recent success of biological control strategies applied to terrestrial problems demonstrates the need for considering them in aquatic environments that now are managed through some of the same dependencies on chemical/physical control concepts previously applied to terrestrial nuisances.

The consideration of biological control strategies to manage Great Lake resources also answers the long overdue cry for an ecosystem approach to management of natural resources (*e.g.*, Risser, 1985). If manipulations of crayfish populations are a viable alternative to the artificial harvest and herbicide treatment of aquatic weeds, then an additional benefit is to be realized. Crayfish are a food source of many warm-water fish sought by recreational fishermen. In addition, crayfish are sought both as a food and as bait for the booming sport fishery industry in the Great Lakes. Therefore, potential benefits to be derived from crayfish stocking as a biological control could include the direct impact on nuisance weed growth and the indirect effects on fishery enhancement. The above discussion also poses the hypothesis that juvenile Lake Sturgeon can act as natural predators on larval stages (ammocoetes) of the sea lamprey in the Great Lakes. If this hypothesis is proven with future research then a reasonable approach would be to consider reestablishment of Lake Sturgeon populations in Lake Ontario through stocking, which is now being done in the midwest (F. Binkowski, Univ. Wisconsin, personal communication, June, 1985). The reestablishment of Sturgeon populations in Lake Ontario would provide added benefits beyond its potential for controlling the sea lamprey nuisance. Deep offshore waters of Lake Ontario are thought to support very low densities of fish (J. Elrod, FWS, Oswego; T. Eckery, DEC, Cape Vincent, personal communication, 1985). Further evidence for this contention is the fact that oppossum shrimp (*Mysis*) and amphipods (*Pontoporeia*) are dense in the deep water habitat, suggesting no major predator in these waters. Establishment of sturgeon populations in Lake Ontario may provide a species that will utilize this deep water habitat, further fortifying some of the trophic interactions of the ecosystem and creating more efficient food chains.

The potential benefits of examining biological control methodologies as management strategies should be obvious. Difference in resources expended (i.e., time and money) for reliance on unnatural control mechanisms (*e.g.*, chemical treatment) versus tapping natural environmental characteristics through biotechnology methods, could be significant. Various management groups presently rely on weed harvestors coupled with applications of Diquot, an aquatic herbicide, to eliminate weed nuisances and pesticides to treat lamprey-infested streams. The mechanical harvestor, besides being expensive, damages fish habitat in the lake areas used and Diquot application restricts swimming for up to two weeks after use. Lamprey treatment impacts not only the target species but also the entire habitat. The development of biological control technology as described above would significantly benefit user groups by providing alternative solutions to nuisance problems that emphasize sustainability of the natural environment.

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Predator-Prey Interactions, Informational Complexity, and the Origins of Intelligence

by Michael H. Robinson

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ABSTRACT

The origins of intelligence, consciousness, awareness and higher brain functions have been a recent focus of attention by biologists and others. In evolutionary perspective they have described the changes in brain structure that have paralleled the growth of sophisticated functions. In addition some consideration has been given to the context(s) in which intelligence and higher functions would confer selective advantages to the possessors. It has been generally concluded that the initial function of intelligence was for the facilitation and exploitation of social relationships within a species. I here argue that intelligence probably arose, in the rainforest, as a means of exploiting complex information to competitive advantage. The rainforest is, and probably was, the most informationally complex habitat on earth. I further argue that rather than intraspecific activities it was interspecific exploitation that intelligence first facilitated. In particular I suggest that it was in the field of food finding and prey recognition that sophisticated learning and cognition evolved.

An outline examination of insect anti-predator adaptations is used to illustrate the possible steps that could have occurred in this process of progressive expansion of brain function. In addition other areas of interspecific interactions conducive to the evolution of intelligence are detailed and it is concluded that consciousness may have a major function as a process to prevent information saturation.

"the Germans . . . also developed a most ingenious paint for their U-boats to camouflage them against infra-red as well as against visible light. If a normal grey-painted ship, which is thus camouflaged well against typically grey sea, is viewed by infra-red it still looks grey but the sea looks blackish. They therefore had to make a paint which looked grey to the human eye, but blackish to the infra-red viewer. They achieved this . . ." Jones, 1979. 410–411.

Introduction

There have been a number of attempts in the last few years to provide a biological and evolutionary background for the evolution of intelligence in animals (for example Beck 1980, Humphrey 1976, Jolly 1966, Moynihan 1976, Robinson 1979, and Sagan 1977). A much earlier treatment of complex learning in animals by Rensch (1950, 1967) is full of insights. In addition, the issues of concept formation, consciousness and animal awareness have been raised as legitimate concerns of biologists in general and behavior students in particular (the whole field was sparked into life by Griffin 1976, see also 1984, and Crook

1980). Although intelligence and the above-used related terms are difficult to define, general agreement exists on the range of phenomena that they comprise. In evolutionary terms one can ask what morphological, anatomical and behavioral characters accompanied the evolution of intelligence and related phenomena, this is the approach of Sagan (1977). This is an interesting question but a more fundamental problem concerns the situations in which intelligence-like properties were likely to have contributed to fitness (or to have acquired survival value; to use a less fashionable term). This approach has been adopted by Jolly (1966), Humphrey (1976), Robinson (1979), and Moynihan (1976). Of these Moynihan's (ibid) is the more comprehensive review that assumes that a plethora of factors was involved. Humphrey (ibid) assumes that intelligence arose to allow primates to cope with the complexities of social interactions.

In this paper I argue that mental processes akin to those subsumed under the term intelligence probably evolved when the ability to process complex information allowed some animals to exploit resources unavailable to other animals. Thus it is argued that the tropical rainforest was the cradle of intelligence since this, by virtue of the extreme range of species diversity and interspecific interactivity is the most information complex of all terrestrial habitats (Robinson 1977, reviews an extensive literature illustrating the interspecific complexity found in tropical rainforest and coral reef ecosystems). Furthermore it is argued that the context of interspecific behavior provided the most opportunity for exploiting the capacity to process complex information, particularly with respect to obtaining food.

This hypothesis implies a rejection of the contrary view that it is in the context of social interactions, within species behaviors, that the ability to process complex information first arose. The main arguments against the function of intelligence being primarily intraspecific (i.e. social) are that selection has favored the evolution of a circumscribed number of unambiguous social signals that facilitate information processing by recipients (displays are displays because they are ritualised). The social context is thus a relatively simple one vis-a-vis information. Moynihan (1970) has emphasized that the total content of display repertories is remarkably constant across wide taxonomic spectra, and over a range of degrees of sociality. On the other hand the continuing arms race between predators and prey has increased, and continues to do so, the complexity of signals generated by most potential prey other than those depending on aposematism.

I came to this view of the origins on intelligence as a consequence of a long-term interest in both sides of the predator-prey interaction (see Robinson 1969a, 1969b and particularly 1970). By reviewing the defensive adaptations of a range of tropical insects this paper provides evidence of the generation of information complexity. This complexification can lead, logically, to two major evolutionary pathways for predators. These are, quite simply, either the path of increasing specialization or the development of complex information processing capacities. In short it is argued that intelligence could have begun its evolution as a means of exploiting the considerable resources potentially available to a sophisticated tropical entomophage. Of course detecting the presence of organisms that have evolved complex anti-predator adaptations is only part of the information processing task involved in food-finding. Most organisms also have to "know" where and when to search. This may involve an extensive stored memory map and a scanning of clock and calendar information. And food-finding is not the only aspect of interspecific activity in which the tropical animal is potentially confronted by a vast array of information that can be used in a way that has great survival value. Many predators are also potential prey and need appropriate defensive behaviors. These defenses may utilize considerable quantities of information (for instance topographic details of home ranges for escape routes and refuges, specialized responses to specific predators and so on; see later). Animals may also need to store and process information about shelter from climatic variables and care of injuries and wounds.

At this stage it is appropriate to consider two ways in which information can be acquired from the environment. It can either be acquired 'phylogenetically', in the lifetime of the species; or in the lifetime of the individual. Lorenz's treatment of this issue (1965) is a really important one. There is little doubt that many animals are hard-wired to be highly successful in niches that require relatively small amounts of information processing. For instance an animal that feeds on only moving insects may (probably does) require a smaller program of food-finding information than one that can find motionless insects. On the other hand the more complex the environment the more there will be niches for animals that can utilize a wider range of information. Thus the tendency that seems to have occurred in the evolutionary process towards increase in brain size, and more individual non-genetic storage of information (see Jerison 1970). These matters are dealt with in the following treatment although not as extensively as they merit. Finally, in considering how animal information processing systems might operate I will review some possible functions of consciousness.

Prey Detection Versus Defenses

Studies of the cues used in prey recognition, whether this is the principal focus or merely an incidental part, lag far behind other studies of the ethology of predation. For instance, only around 8% of Curio's (1976) review of predation behavior deals with prey recognition per se. This relative neglect is not due to the fact that the subject lacks intrinsic interest. For example, food-finding has been most heavily studied in birds. Many specialized entomophages are birds, yet we know little about how they recognize prey. Tinbergen (1963) has stressed our ignorance: "We know that young birds have, at the start, a very "open mind" with regard to food; they respond to an enormous variety of objects, edible and inedible alike, and learn to confine themselves to those they find edible. My suggestion is that we have as yet no more than the faintest idea of the kinds of things such birds learn when young". There are some exceptions, see for instance, Greenberg (1984) but this is still true in essence. In the absence of direct studies it is tempting to make inferences about the behavior of predators from the presumed anti-predator adaptations of their prey. This kind of deduction is often both logical and useful. Thus anyone encountering the submarine painted in the manner described at the head of this paper would be able to deduce that the predator had, in this case, detectors capable of operating in visible light and the infra-red. Similarly if the so-called Stealth Bomber is ever built, an examination of its structure could lead to the deduction that radiodetection devices (Radar) exist. Examples of successful deduction of function from structure are readily found in the literature on recent military intelligence operations (see Jones, 1979, for intricate examples). (There are perils in deducing function from structure. Wood-Mason in 1878, published a description of a phasmid that he claimed was specialized for aquatic life. It had a flattened body, with a concave undersurface fringed with hair, and flattened limbs. All these adaptations are found in mayfly larvae that live in streams, where they are aquatic adaptations. However, in the case of *Prisopus berosus* they are adaptations to profile concealment when the insect is in its concealment posture, see Figure 16 in Robinson 1969a).

Despite these problems there are good examples of verified deductions of function from structure in relation to insect defensive systems. Thus color-matching camouflage, counter-shading, Batesian mimicry, and aposematism have all had their deduced functions subjected to experimental testing (rather than cite a plethora of references the reader is referred to Edmunds 1974, and Curio 1976, for examples and bibliographies). A particularly interesting example of such deduction concerns the function of eye-like markings in lepidoptera. These have long been regarded as startle devices, when large and closely similar to the vertebrate eye, and as deflection devices when small and generalised (Blest 1957). Blest (ibid) was able to show, experimentally, that the startle effect was greatest when the resemblance to an eye was closest.

A number of major visual defenses are still, to my knowledge, untested. These include outline concealing structures (Figure 1), obliterative patterning, flash coloration, and behaviors such as dash and freeze locomotion to name but a few. It is probable that obliterative patterning (= disruptive coloration) has been tested in its military applications. My own studies of the mimetic postures of stick- and leaf-mimicking insects (1969a, 1969b, 1970, 1973, 1981a) including data on more than fifty species of phasmids from Papua New Guinea that is as yet unpublished because of the impossibility of obtaining species identifications, have led me to conclusions about predator behavior. These can be summed up very simply; the insects have elaborate and complex devices that apparently serve to conceal structures that are typical of insects in particular and many anthropods in general. The structures concealed are segmentation, legs, heads, antennae and (often) wings. The concealment of these structures occurs in some phasmids that are not specialised stick and leaf-mimics and could have preceded the evolution of such mimicry although it now enhances the disguise. Functionally such concealment could have evolved in cryptic insects to enhance their crypticity and then been a preadaptation to plant part mimicry (= disguise). This argument is presented in detail in Robinson (1969a, 1969b) and other examples are cited by Edmunds (1974). A revised outline of how stick and leaf-mimicry could have evolved is shown in Figures 2–6.

Merely looking at the visually operating systems of primary defence found in terrestrial arthropods allows us to make some guesses about how prey detection abilities could operate in predators. Thus the existence of color-matching camouflage, diurnal immobility, disruptive patterning and countershading suggests that visually hunting predators can recognize prey by their shape. A huge literature in experimental psychology suggests that animals can learn to respond to a considerable catalog of shapes or patterns. Humans also have an impressive ability to do this (Haber 1970), it is a right brain function. However a predator responding to the shape of a prey organism in the tropics would be confronted with an enormous array of specific learning tasks. It could encounter a multitude of species. (Recent studies of tropical forest insects in the canopy, by Erwin (1982, 1983), have suggested that estimates of the total number of insect species in the world needs upgrading from 1.5 million to as much as 30 million; most of these are in the tropics). Furthermore the hunting pressure of predators may have

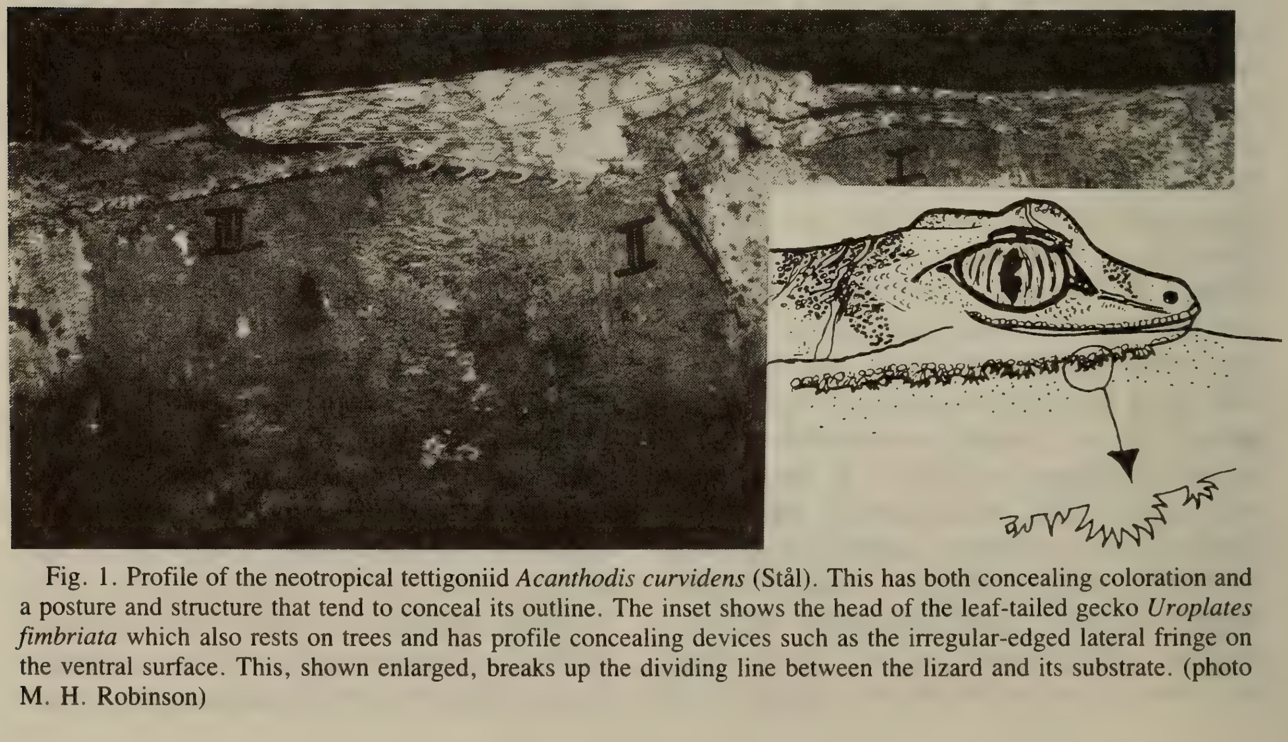

Fig. 1. Profile of the neotropical tettigoniid *Acanthodis curvidens* (Stål). This has both concealing coloration and a posture and structure that tend to conceal its outline. The inset shows the head of the leaf-tailed gecko *Uroplates fimbriata* which also rests on trees and has profile concealing devices such as the irregular-edged lateral fringe on the ventral surface. This, shown enlarged, breaks up the dividing line between the lizard and its substrate. (photo M. H. Robinson)

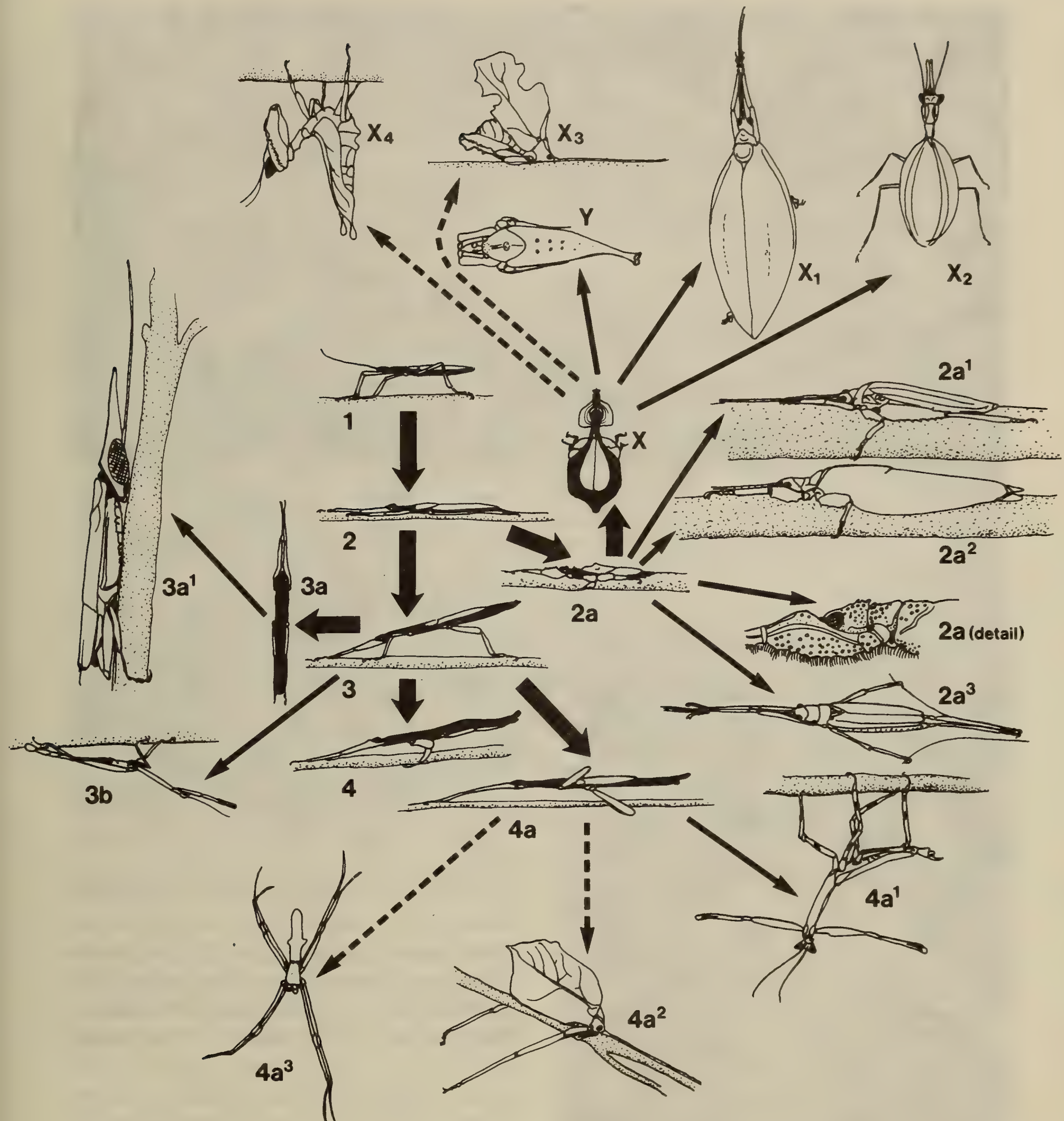

Fig. 2. The evolution of stick- and leaf-mimicry in the insect Order Phasmida and convergent postures found in other arthropods. The central grouping of insects with solid black bodies connected by broad arrows is the phasmid element of the diagram. The other figures show anatomically and/or posturally convergent forms. Explanation in Appendix 1.

tended to accentuate differences between appearances, by apostatic selection (Clark 1969), thereby increasing the learning task confronting predators, by producing aspect diversity (Rand 1967, Rickleffs and O'Rourke 1975). Species diversity and aspect diversity combine to produce massive informational complexity. To treat this kind of complexity there are at least two conceivable mechanisms. One is to store information about all the prey that

Fig. 3. The tettigoniid *Acauloplacella immunis* Brunner, from New Guinea, in its cryptic posture. The wings are flattened so that they tent over most of the intermediate and posterior legs and touch the leaf surface, producing a very low profile. Note the position of the anterior legs (compare with X_1 on Figure 2). (Photo M. H. Robinson)

Fig. 4. The Australian preying mantis *Neomantis australis* (Saussure and Zehntner) which has a permanently flattened posture for the wings, this is essentially similar to that shown in Figure 3. (compare with X_2 on Figure 2). (Photo M. H. Robinson)

are encountered and have an efficient system of reviewing the stored information (see later, for comments on this possibility). The other is to group the information into subsets and act on these; this is the process of stimulus generalization or nonverbal concept formation. I am inclined to think that predators may have an impossible task if they rely on individual recognition of prey types. Scanning the floppy-disc of memory could be an impossibly complex operation when the data base is massive. It would help to be able to recognize some general characteristic of subsets of the general assemblage of prey. To do this would require the beginnings of intelligence. What are some of the possible bases for subsets?

Possible Simplifying Mechanisms

One, of course, is the recognition of the insect ''taxonomically'' by its diagnostic parts. This is suggested by the extreme modifications for concealing these parts which are discussed above, and illustrated in Figures 2–6. There is, so far, little evidence that this is how prey recognition works. However, I have carried out some experiments the results of

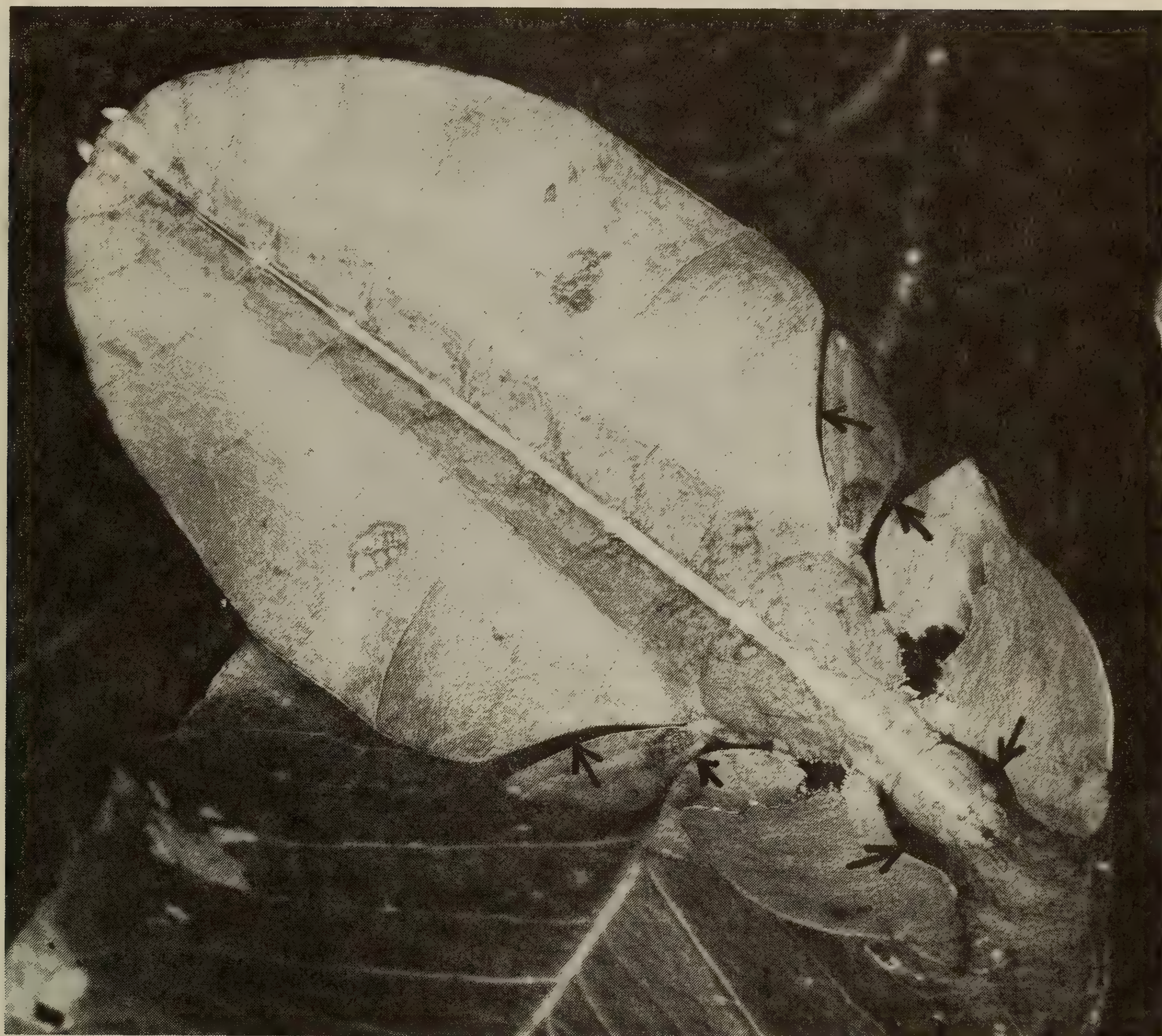

Fig. 5. Leaf insect from New Guinea, note the huge gauntlet-like dilated and flattened femora (arrowed) of all six legs. The arrows show the direction in which the legs move to form the resting outline shown in X of Figure 2. (Photo M. H. Robinson)

which are at least suggestive (Robinson 1970). These show that some predators can use the presence of heads or legs to find otherwise concealed prey. There are also experiments that show that even creatures with such small brains as jumping spiders (salticidae) respond to leg-like projections on models when attacking prey (Drees 1952). And a number of birds show head-recognition in the manipulation of prey. A further possibility is that predators may respond to the bilateral symmetry of insect prey. Cryptic patterns on the wings of moths are invariably bilaterally symmetrical. The use of symmetry as a detection device can be easily demonstrated in human subjects confronted with photographs of cryptic insects. It would provide an almost universal cue in the detection of immobile cryptic prey since the developmental processes of insects seem to rigidly produce symmetricality of patterning. Significantly, military camouflage patterns avoid this symmetry in moth-like objects as shown in Figure 7. Elegant experiments by Delius and Nowak (1982) have shown that pigeons can learn to recognize symmetry and make discriminations between patterns, that are based on symmetry. It has also been shown that pigeons can solve inversion problems at least as well as humans (Hollard and Delius 1982).

Thus it is possible that predators may have an 'averbal taxonomic ability' (named after Koehler's 'averbal counting ability' concept, see Rensch 1950) and also an 'averbal sym-

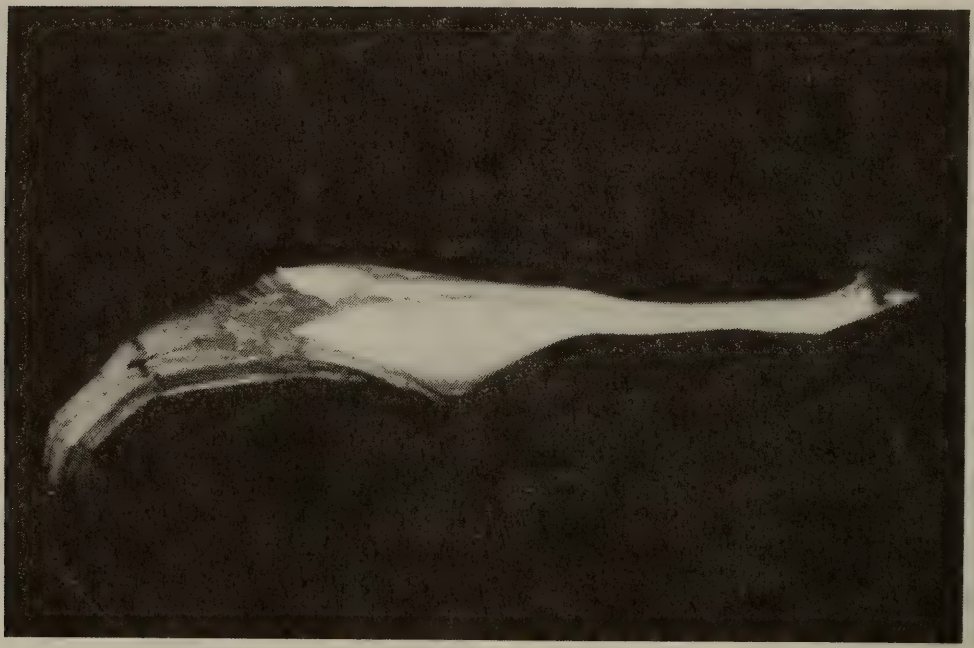

Fig. 6. The orb-web spider *Arachnura melanura*. This sits at the center of its web with all its legs folded against themselves or the margins of the body. Legs I and II project forwards, legs III and IV fold against the body. The spider is bright yellow and flower-like. (Photo M. H. Robinson)

metry discrimination'. These abilities, it can be argued, could imply complex mental phenomena. If it turns out that visually hunting predators can store and review large numbers of bits of information, in a 'directory of prey shapes', which is not impossible, then they will prove to have an information processing system that could be an important adjunct/ precursor of induction.

It has been suggested, for two reasons, that orangutans may be intelligent (Galdikas 1978). One reason is that although they are the least social of the great apes they have to store social information for long periods between encounters. I do not find this very convincing. On the other hand the fact that they may have a sense of 'averbal botanic taxonomy' to cope with a plethora of plants is suggestive. (For comments on orangutan intelligence see also Maple 1980).

Other Complex Information Processing Tasks

Food finding is not the only situation that could evoke the evolution of intelligence. I suggested earlier that there were a number of interspecific tasks that faced many animals and were of great survival importance. In many of these cases the ability to store, review and "abstract" complex information could be crucial to success. Admittedly animals can be well adapted in tropical forest niches without apparently using this information, but its existence opens up the possibility that a clever animal would have a greater evolutionary potential. In these cases, reviewed below, conventional learning paradigms may be inapplicable—animals may need new types of plastic behavior to exploit the new opportunities to the full. A case in point involves the acquisition of detailed familiarity with a home range (familiarity with a territory may be a similar phenomenon, worth consideration at length, but omitted here for space considerations). Many mammals show detailed familiarity with the topography and contents of their home range. This knowledge can be of value to them in locating food and in the urgent situation of finding escape routes and refuges when pursued, or confronted, by a predator. It is not clear that the kind of learning involved in this kind of information acquisition fits any conventional paradigms. The learning of maze layouts by rats, which were merely given maze experience without extraneous re-

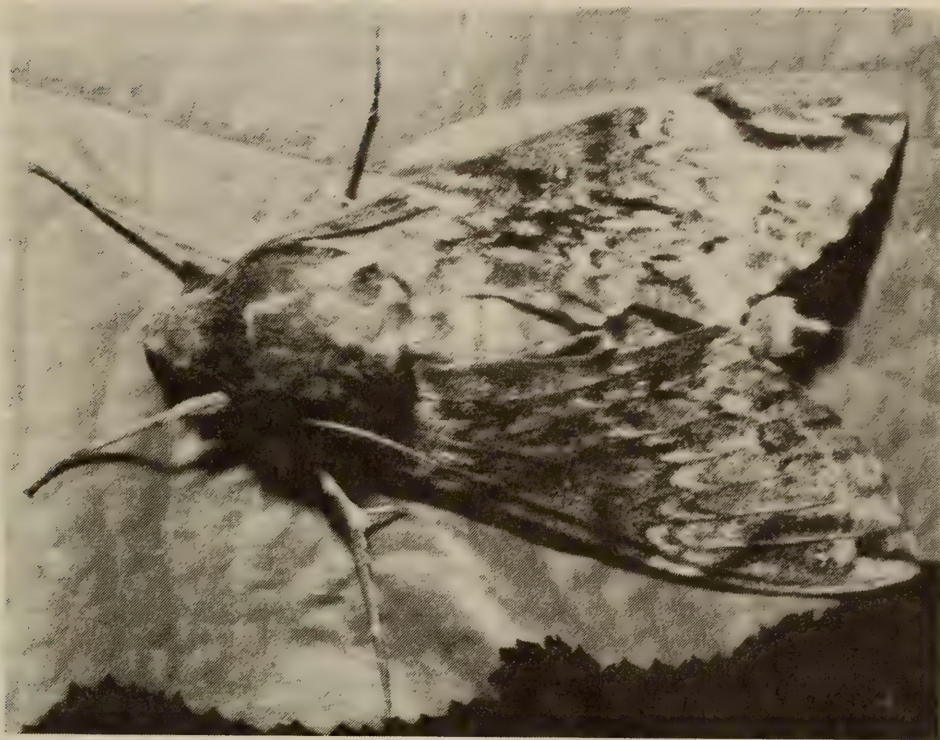

Fig. 7. Photograph of a sphinx moth showing symmetrical markings and a delta-winged bomber showing asymmetrical camouflage markings (moth photo M. H. Robinson, aircraft courtesy of National Air and Space Museum, Smithsonian Institution).

inforcement, was called 'latent learning' by Hinde (1966). He has since pointed out some of the problems involved in this kind of categorization but argues that 'place learning' could best be explained in cognitive rather than stimulus-response terms (Hinde 1970). Mackintosh (1983) remarks of these phenomena "the topic of maze learning has shown a marked revival in recent years, partly due to the suggestion that such learning depends on the establishment of a cognitive map of the rat's environment". Bernard (1983) still uses the term latent learning, cites a 1930 experiment as an example, but states that "a detailed geographical knowledge of the home area could be crucial in escaping from pred-

ators''. It seems to me that this kind of conventionally unrewarded learning is of great interest. There is a dearth of field studies on the extent to which free-living animals use a cognitive map. Many observations suggest that they do. It is tempting to speculate, by introspection, that some kind of mental reward may accompany such types of learning. The possibility that some kinds of locality learning may be of survival value only in the context of extremely rare events is raised by the use of water holes by baboons in East Africa. This rare use may occur during droughts that may be many, many years apart. Here the old members of a troop prove their usefulness as repositories of knowledge (Altmann and Altmann 1970). The occurrence of rare climatic events even in purportedly stable, humid tropics (Rand and Rand 1982), suggests that animals could gain survival advantages from long term knowledge of resource distribution.

Lorenz (1981) has argued that exploratory behavior plays an important part in the kinds of mental cartography described above, and some classic treatments suggest that curiosity is an important appetitive behavior. The linkage or parallel of exploration to play is also a link to intelligence.

Tool use by animals (Beck 1980, Griffin 1984) may be another instance where intelligence may immediately confer an adaptive advantage. Insight learning may give an opportunity to exploit resources that are out of reach or otherwise unavailable. The classic experiments of Kohler (1925) are still cited as examples, although Goodall's chimpanzee's termite catching behavior (1968) may have arisen this way.

Animals also have to cope with climatic variables that affect the distribution of food supplies. Species that range widely to exploit resources that are localized in space and time could benefit from having a capacity for learning phenological sequences of flowering, fruiting and leafing (for instance). Using a calendar of biological seasonality would be as useful as possessing a cognitive map of resource distribution. Knowledge thus acquired could guide an animal to flowers, fruits and new leaves or to the animals (insects perhaps) that feed on them. Of course simple trial and error patrolling would achieve the same end, but could involve the expenditure of a great deal more energy. A calendar would be more efficient.

Most animals face the possibility, in their lives, of experiencing injuries or wounds. Predators, in particular, because of their extreme reliance on maximum efficiency in capturing prey, cannot afford debilitating injuries. They must therefore not only learn what organisms are edible but also what organisms they should not attack. The avoidance learning of distasteful and dangerous organisms may be simplified by the evolution of warning coloration by prey organisms. On the other hand the existence of Batesian mimicry and other kinds of false warning coloration means that a ''simplistic'' response to aposematism could result in a predator ignoring a whole range of potentially edible organisms. Although there has been extensive research showing that predators learn to generalize aversive responses to aposematic prey, there have been few studies of whether sophisticated predators can learn to detect deception. I suspect that such discrimination will eventually be discovered. My own studies suggest that tamarins (small monkeys) are not fooled by eye-markings and startle displays, although birds are (Robinson 1966, Blest 1957). Furthermore there is a whole range of insects that bring stings and other weapons into play only as secondary defense and the alpha predator needs to be able to discriminate between these and harmless look-alikes. It is in the tropics that by far the greatest number of kinds of potential prey could either be dangerous or be falsifying information (lying) about their dangerousness. Thus the need for intelligent behavior in detecting food is likely to be paralleled by a similar need in determining sources of danger. One of the most intriguing aspects of animal behavior is the care of injuries and wounds. This care is of immediate adaptive value. As far as I know it has not been studied by ethologists; it should be possible to do so without inflicting pain and injury on experimental animals.

This brief review suggests that the begin-

nings of tendencies to process complex information, through systems of complex learning and cognition, could provide a whole series of adaptive windows for the possessor in fields other than food-finding. This raises the question of the evolution of consciousness, does this have some relationship to information processing?

Consciousness

Mayr (1982) has argued that consciousness is undefinable and, by implication, not susceptible to discussion or study: "As far as consciousness is concerned, it is impossible to define it . . . therefore detailed discussion is impossible." Griffin (1984) ranges over a whole series of attributes of consciousness without approaching a single satisfactory definition. Crook (1980) also uses a multi-component definition.

To avoid definitional problems it is perhaps appropriate to consider particular aspects of consciousness. Thus there is the question of memory-awareness as it might be called. One introspectively available datum is that only a small portion of the memory store is available to our minds at any one time. It is as if a huge memory store (nonconscious) were scanned and the appropriate piece of information were brought onto the screen of the mind for conscious viewing. The impossibility of being simultaneously aware of the entire contents of a memory store suggests one major function of consciousness. It allows for ordered review of the information that is necessary for action. It is difficult to imagine any other mechanism that could allow selective review of stored information in animals. To the computer enthusiast, reading off the sequential content of a ROM provides a bewildering succession of information. The brain does not consciously work that way. Information is not presented in massive successional series. The extensive content of the nonconscious visual memory banks is nicely illustrated by the act of reviewing a box of color slides from, say, twenty years ago. Despite the enormous volume of visual experiences that have occupied the twenty intervening years most people will recall all the scenes on a roll of film and be able to add verbal detail to describe them (I owe this illustration to Blakeslee 1980). This is, coldly considered, an amazing feat. Lorenz (1981) has drawn attention to a similar phenomenon: "It borders on the miraculous the way in which gestalt perception can abstract configurations of distinctive features from a chaotic background of accidental stimulus data, and then retain these over the years." It is interesting that for most people sights are retained in greater profusion than sounds and smells. We may be impinging on a device that once served our predatory past. Perhaps consciousness is not the problem; perhaps nonconsciousness is really the important adaptation. Without it all animals could be in a state of constant information shock, overwhelmed by the simultaneous input of countless bits of stored data.

Conclusion

If intelligence is a response to information-processing in an information-rich environment this may have been only its originating function. Because the adaptive steps to higher learning conferred advantages in enabling the possessor to exploit new resources, there is no need to assume that this was the only function. In postulating the origins of intelligence we have merely described an interspecific climate that favored the start of an evolutionary progression. The milieu of increasing social complexity may then have added its synergism to that of interspecific complexity. Humphrey (1975) and Jolly (1966) have, perhaps, identified a later stage of the evolutionary progression.

I have suggested elsewhere (Robinson 1977, 1981b) that there is a fundamental difference between tropical biology in complex habitats (rainforests and coral reefs) and the biology of all other regions. I have characterized this difference as being reflected in the utter complexity of the biotic component of the habitat.

The suggestion made throughout this paper is that one way of coping with biotic complexity is for some animals to have a capacity for plastic behavior and for individuals to store, process and adaptively reorganize information during their lifetimes. (In contradistinction to the phylogenetic processing of information involved in preprogrammed behaviors.) When animals that evolved in information-rich environments later moved into relatively simple ones, those that had evolved sophisticated cognition and intelligence may have had a surplus capacity. This release from pressures of survival may have been analogous in many ways to infancy in higher mammals. It could have been a period in which mental exploration and intellectual play were possible for the first time. It could have been the point at which abstract thought had its first flowering. It may have happened when our ancestors moved from the information-rich forests into the savannas.

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Appendix I

The Evolution of Stick- and Leaf-mimicry in the Phasmids and Convergent Postures in Other Arthropods

The argument is simply that, from a relatively generalized ancestor (1), adaptations for profile concealment in cryptic postures led to apparent elongation. These adaptations included extension of legs I in front of the head (which incidentally concealed its structure and the antennae) and posterior extension of legs II and III apposed to the body as shown in 2. This concealed the legs and profile. Together these behaviors enhanced the stick-like appearance of the resting insect. A further step would be to become increasingly flattened (as in element 2a and detail: this is the insect *Prisopus berosus*, referred to in the text, that was once assumed to be aquatic). Dorso-ventral flattening could be a pre-adaptation to leaf-mimicry as in X. Once the insect became elongate and had appropriate leg postures the next evolutionary step could be the one to stand-alone stick mimicry shown in element 3. Once this is achieved the insect is no longer cryptic but a true mimic and can be protected from predators by its resemblance to the inedible rather than merging with a background. Disguise is substituted for concealment. Element 3a is the total stick position assumed by many phasmids after dropping from a substrate—all legs are folded against the body. Stages 4 and 4a are a further enhancement of stick posture 3. They involve either structural concealment or structural and postural concealments of other legs in a stick-with-branches position. The insect shown in element 4a is illustrated in detail by Robinson 1969a.

Around the central block of phasmids the other drawings show similar postures and structures found in other arthropod groups, $2a^1$ and $2a^2$ are tettigoniid resting postures that exactly parallel that shown in 2a. Element $2a^1$ is the tettigoniid shown in Figure 1 while element $2a^2$ is a tettigoniid from Asia (see Robinson 1977 for details). Element $2a^3$ is another tettigoniid that assumes an essentially similar posture to 2a but which rests on flat rather than curved surfaces (from Robinson 1969b). Elements $4a^1$, $4a^2$ and $4a^3$ show leg concealment postures in which legs become branches associated with a stick or leaf. Element $4a^1$ is a West African mantid that assumes a stick-with-branches position (from Robinson 1966), $4a^2$ is a dead leaf katydid (from Robinson 1969a) and $4a^3$ is the spider *Dinopis rufipes* which hangs from vegetation with its legs grouped into four stick-like units (original, from a color slide). Element 3b is a stick posture found in stick-like mantids which involves the protraction of both legs I in a similar manner to that shown in 3. Element $3a^1$ shows the grass dwelling mantid *Pyrgomantis pallida* in its resting posture which is essentially similar to 2 and 3a but with the

anterior legs folded beneath the thorax and very closely apposed to it (original from a color slide).

Elements X_1, X_2 two insects, a tettigoniid and mantid respectively, that are at a stage that could lead to the evolution of leaf mimicry. Both have broadly flattened wings that are leaf-like and cover the body and parts of the legs. Compare with Figures 3 and 4. Elements X_3 and X_4 are functionally leaf mimicks, with complex leg concealment postures (see Robinson 1969a for details). Element Y is the orb-weaving spider *Arachnura melanura* that is a flower mimic with a complex mimetic posture involving leg concealment and specialized form (compare with Figure 6).

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Enhancement of Mitogen Responsiveness in Mice Exposed to Low Concentrations of Cadmium in Drinking Water

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ABSTRACT

The effects of cadmium on the immune system have been extensively studied with reports of both immunoenhancement and immunosuppression associated with cadmium exposure. These studies have generally used a cadmium dose well above normal levels of exposure. In the present study, we report the immunologic effects of exposure to very low levels of cadmium using the lymphocyte transformation test as a reflection of immunocompetence. Male Balb/c mice were exposed to cadmium, 0, 0.01, 0.1, 1.0 and 10 ppm, in drinking water for 4–5 weeks at which time the mitogen- and MLC-responsiveness of their splenic mononuclear cells was determined in a standard lymphocyte transformation test. Cadmium exposure was associated with an enhanced response to both LPS and Con A. The LPS response of mice exposed to 10 ppm cadmium was statistically significantly higher than that of non-cadmium exposed mice. Cadmium exposure had no effect on either unstimulated DNA synthesis or that induced by co-culture with allogeneic or syngeneic, irradiated splenocytes. These results suggest that the immune system may be modified by very low levels of cadmium in the environment.

Introduction

As a heavy metal of environmental concern, the effects of cadmium on the immune system have been extensively studied. Cadmium exposure significantly alters resistance to infection following bacterial (Cook et al., 1975) or viral (Gainer, 1977) challenge, resistance to tumor challenge (Kerkvliet et al., 1979) the humoral (Koller, 1973; Koller et al., 1975) and cell-mediated (Muller et al., 1979) response to immunization with defined antigens, and macrophage function (Koller and Roan, 1977; Loose et al., 1977). Generally, cadmium is reported to suppress the immune system, however, a number of studies have reported an immunoenhancing effect of cadmium exposure (Koller et al., 1976; Exon et al., 1979). A review of the literature suggests that the immunologic effects of cadmium exposure are dependent on a variety of factors including strain and species of animal, nature of the immunologic challenge, and the regimen of cadmium exposure.

Immunotoxicologic studies of cadmium have generally used a cadmium dose below that associated with clinical toxicity but well above normal environmental levels of exposure. We have been particularly interested in the effects of low level cadmium exposure on the functional response of lymphocytes. Low concentrations of cadmium added *in vitro* to cultured murine splenocytes, are associated with enhanced lymphocyte transformation while higher concentrations totally inhibit both unstimulated and mitogen-stimulated DNA, RNA and protein synthesis (Shenker et al., 1977; Gallagher et al., 1979). In addition, the enhanced rejection of allogeneic skin grafts (Balter et al., 1982) and decreased mortality rate following MOPC-104E tumor cell challenge (Matarazzo et al., 1979) in mice exposed to 0.01 to 1.0 ppm cadmium in drinking water suggest that very low levels of cadmium exposure may enhance immune responsiveness. In the present study we report an enhanced splenocyte response to mitogen stimulation in mice exposed to low levels of cadmium in drinking water.

Materials and Methods

Male Balb/c mice, 5–6 weeks of age were obtained from Harlan Spraque-Dawley (Walkersville, MD) and housed in departmental animal quarters. After 5 days on standard laboratory chow and water, ad lib., the mice were randomly divided into treatment groups, 12 per group, and placed on drinking water containing 0, 0.01, 0.1, 1.0 or 10 ppm Cd^{2+}, as its chloride salt, in 3x glass distilled water. The water stock contained less than 0.01 ppm, and the chow, 0.4 ppm cadmium.

After 4–5 weeks of cadmium exposure, the mitogen- and mixed lymphocyte (MLC)-responsiveness of the Ficoll-Hypaque separated mononuclear cell fraction of each mouse spleen was determined. The washed mononuclear cells were resuspended at a concentration of 2×10^6 cells/ml in RPMI 1640 supplemented with 20% fetal calf serum and 2% of an antibiotic solution containing 5000 U/ml penicillin and 5000 ug/ml streptomycin. Cell number and viability were determined by hemacytometer counting and trypan blue exclusion. Cell cultures were established in quadruplicate in 96 well microtiter plates with each well containing 0.1 ml of the cell suspension and 0.1 ml of stimulator, either mitogen or allogeneic or syngeneic cells prepared in RPMI. Control (unstimulated) wells received 0.1 ml of RPMI. The mitogens, Lipopolysaccharide W, E. coli 055:B5 (LPS, Difco) and Concanavalin A (Con A; Pharmacia), were used at previously determined optimal mitogenic concentrations of 25 and 5 ug/ml, respectively. Allogeneic and syngeneic stimulator cells were obtained from the spleens of nonmetal exposed C57Bl and Balb/c mice. Stimulator cells were prepared at a concentration of 2×10^6/ml and irradiated (2000 rad, Cesium source) before use.

The microtiter plates were incubated at 37°C in a humidified atmosphere of 5% CO_2 in air for 3 days for mitogen-stimulated cultures and 5 days for MLC cultures. Lymphocyte transformation was estimated by measuring the incorporation of tritium-labelled thymidine, (^{3}H-TdR) into DNA. For this purpose 1 uCi

^{3}H-TdR (24 Ci/mmole, Amersham) was added to each well 18 hours before termination of the culture. DNA was collected on glass fiber filters using an automated cell harvestor (Bellco) and the radioactivity associated with each filter was measured by liquid scintillation counting. The mean ^{3}H-TdR incorporation of quadruplicate wells was calculated and used as a single determination.

Since the lymphocyte transformation test is at best associated with a large variability, the study was designed to control as many parameters as possible. Each experimental run contained 2 animals from each treatment group, processed in a random order. A single stock of culture medium, serum, mitogens, etc. was used throughout the six runs. Due to the variability associated with determinining cell concentration by hemacytometer counting, each cell suspension was sampled and counted independently by two individuals and then recounted if the counts varied by more than 10%.

The stimulation index (SI) for the mitogen and MLC responses of each animal was calculated by dividing the ^{3}H-TdR incorporation in the presence of the stimulator by the unstimulated ^{3}H-TdR incorporation for that animal. The results were analyzed for an effect of cadmium exposure using a one-way analysis of variance. Individual cadmium treatment groups were compared to the 0 ppm control using the L^2 statistic for contrasts (Dixon and Massey, 1969). Differences were considered significant when $p < 0.05$.

Results

Cadmium exposure was not associated with any clinical toxicity although 2 of the animals in the 0.01 ppm treatment group died of an apparent infection. There was no significant difference in the spleen weights among the treatment groups.

The gross ^{3}H-TdR incorporation in unstimulated, LPS- and Con A- stimulated cultures for each mouse are presented in Figure 1a, b, and c respectively. The mean responses for each group are represented by the bars in Figure 1 and listed with the standard errors in Table 1. Within each treatment group there was considerable variation in the magnitude of the DNA synthetic response as measured by ^{3}H-TdR incorporation. This animal to animal variation was not related to differences between experimental runs or the order of processing within an experimental run. Regression analyses were performed to determine whether the animal to animal variation in the magnitude of the mitogen and MLC responses was related to the magnitude of the unstimulated ^{3}H-TdR incorporation of the animals; i.e., were the animals with high values of unstimulated ^{3}H-TdR incorporation also the animals with the high values of mitogen- or MLC-induced incorporation and those with low unstimulated responses the ones with low responses to stimulation. The regression analyses (stimulated incorporation as a function of unstimulated incorporation) indicated that there was no correlation between the magnitude of the unstimulated ^{3}H-TdR incorporation and that of the stimulated cultures.

In spite of the range of responses within cadmium-treatment groups, an analysis of variance of the results of the mitogen study demonstrated a statistically significant treatment (cadmium) effect on each parameter measured: unstimulated, LPS- and Con A-stimulated ^{3}H-TdR incorporation. When specific treatment groups were compared, the ^{3}H-TdR incorporation of unstimulated cells from mice exposed to 0.01 ppm cadmium and the LPS-stimulated incorporation by splenocytes from mice exposed to 10 ppm cadmium were each significantly different from the corresponding values obtained from control mice (0 ppm cadmium).

The MLC response of splenocytes from cadmium-exposed mice to non-metal exposed allogeneic (C57BL) and syngeneic (Balb/c) splenocytes as well as the ^{3}H-TdR incorporation in unstimulated 5-day cultures appear in Table 2. There was no significant effect of cadmium treatment on the unstimulated ^{3}H-TdR incorporation or that induced by co-culture with allogeneic or syngeneic cells.

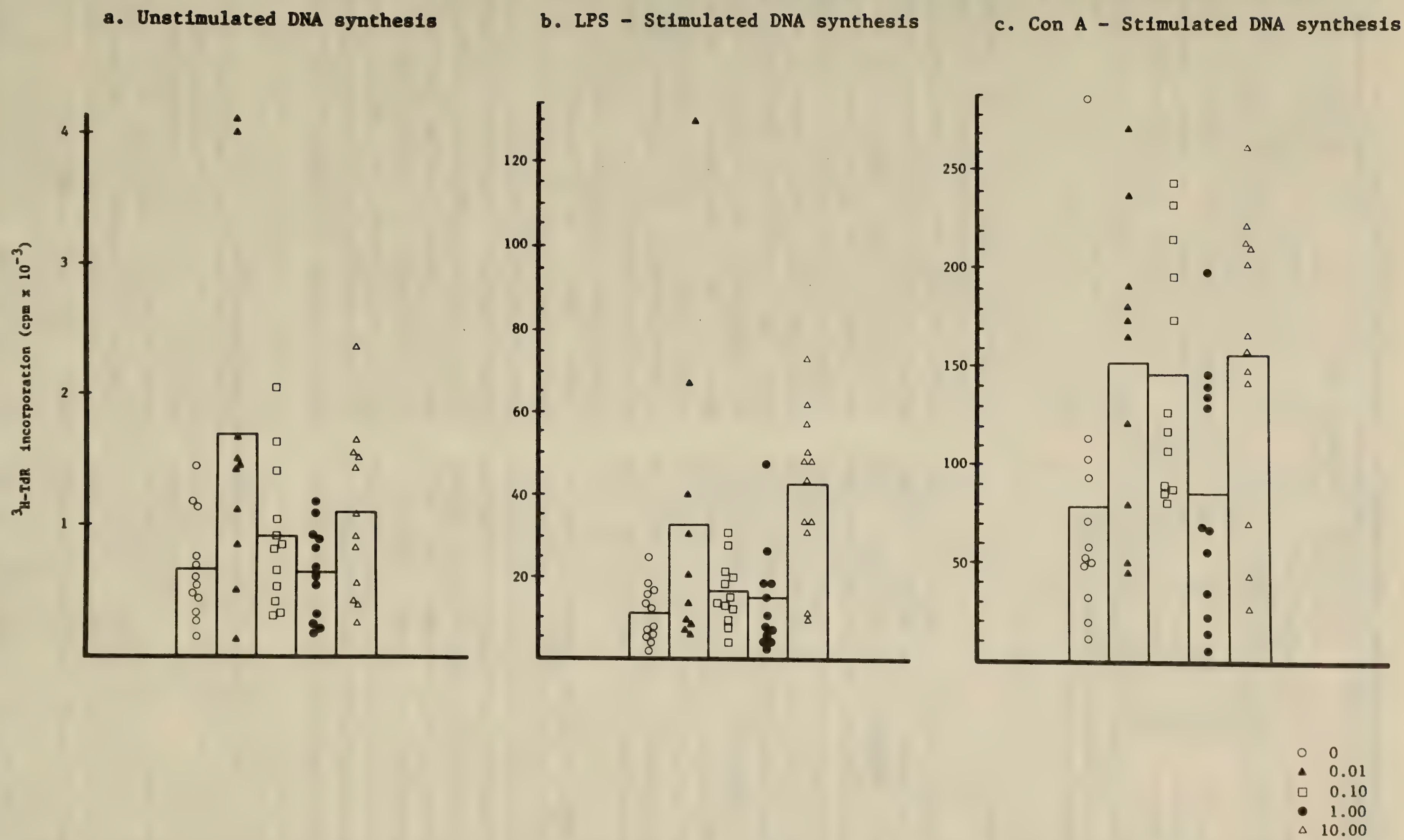

Fig. 1. ^{3}H-TdR incorporation by splenocyte cultures from individual animals exposed to drinking water containing 0 (○), 0.01 (▲), 0.1 (□), 1.0 (●) or 10 (△) ppm cadmium. 1a. Unstimulated cultures. 1b. Cultures containing 25 ug/ml LPS. 1c. Cultures containing 5 ug/ml Con A. Note the different scales on the ordinates.

TABLE 1.—Mitogen Response of Splenocytes from Cadmium-Exposed Mice

Treatment Group (ppm Cd^{2+})	n	^{3}H-TdR Incorporation (cpm) Mean ± SE			Stimulation Index Mean ± SE	
		Unstimulated	LPS	Con A	LPS	Con A
0	12	665 ± 114	10214 ± 1966	78073 ± 20923	17.8 ± 3.2	134.1 ± 24.4
0.01	10	1682 ± 424[a]	32963 ± 12410	150690 ± 23989	27.9 ± 9.3	170.5 ± 53.4
0.10	12	908 ± 156	15939 ± 2295	145253 ± 17785	27.4 ± 6.5	263.1 ± 71.4
1.00	12	633 ± 101	13880 ± 3777	83772 ± 17913	31.9 ± 9.2	202.6 ± 54.6
10.00	12	1079 ± 183	42149 ± 5483[b]	154148 ± 21444	50.5 ± 9.4	193.0 ± 37.1

[a]Significantly different from 0 ppm, $p < 0.05$.
[b]Significantly different from 0 ppm, $p < 0.01$.

Discussion

Splenocytes from mice exposed to 0.01–10 ppm cadmium in drinking water had significantly enhanced DNA synthesis in response to LPS- and Con A-stimulation compared to splenocytes from non-metal exposed controls. The one-way analysis of variance also demonstrated significant cadmium effect on the magnitude of 3-day unstimulated DNA synthesis. Cadmium exposure had no effect on the magnitude of the DNA synthetic response to allogeneic or syngeneic cells or on the unstimulated DNA synthesis in the 5-day cultures.

The data from the mitogen cultures has been presented as the cpm of ^{3}H-TdR incorporation for each animal (Figure 1) so that the individual variability within treatment groups and the differences in the response between treatment groups is readily evident. When specific treatment groups are compared statistically to the non-metal exposed control group, the large within group variabilities in combination with the reduced n results in only 2 statistically significant comparisons: the LPS response at 10 ppm and the unstimulated ^{3}H-TdR incorporation at 0.01 ppm. This statistical analysis in combination with the patterns of response of individual animals suggests the following conclusions: (1) The LPS response of animals exposed to 10 ppm cadmium is significantly higher than that of non-cadmium exposed animals. This conclusion is statistically valid and supported by the distribution of the response of individual animals: 10 out of 12 animals exposed to 10 ppm cadmium have a response greater than the highest response observed in non-exposed animals. (2) Cadmium exposure tends to enhance the Con A response. Eight out of 10 animals in the 0.01 ppm treatment group, 12 out of 12 in the 0.1 ppm group and 9 out of 12 in the 10 ppm group have a Con A response which is greater than the mean response of the 0 ppm treatment group. Although these differences are not significant by comparisons based on the analysis of variance, they are significantly different when Student's t-test is used to compare the means. (3) Cadmium exposure has

TABLE 2.—MLC Response of Splenocytes from Cadmium-Exposed Mice

Treatment Group (ppm Cd^{2+})	n	^{3}H-TdR Incorporation (cpm) Mean ± SE			Stimulation Index Mean ± SE	
		Unstimulated	C57B1	Balb/c	C57B1	Balb/c
0	12	804 ± 163	3032 ± 416	718 ± 133	7.0 ± 1.9	1.2 ± 0.3
0.01	10	751 ± 176	4993 ± 1411	952 ± 282	9.2 ± 2.5	1.6 ± 0.3
0.10	12	731 ± 228	4452 ± 1149	675 ± 129	8.7 ± 2.1	1.3 ± 0.2
1.00	12	482 ± 97	3360 ± 663	569 ± 119	10.2 ± 2.7	1.9 ± 0.6
10.00	12	988 ± 214	3849 ± 569	725 ± 108	5.7 ± 1.3	1.0 ± 0.2

no effect on unstimulated ^{3}H-TdR incorporation. Although in the 3-day cultures, the mean incorporation of the animals exposed to 0.01 ppm cadmium is statistically significantly higher than that of non-cadmium exposed animals, the mean response of the cadmium group has been substantially increased by the response of two animals with ^{3}H-TdR incorporation values of more than twice that observed in any other animal in this study. These two animals were housed in the same cage as the two animals which died during the study and there is, therefore, the possibility that they had a subclinical infection which resulted in splenocytes with a higher baseline reactivity. If these two animals are dropped entirely from the one-way analysis of variance, there is no cadmium treatment effect on unstimulated DNA synthesis; the significant effect of cadmium on the mitogen responses, however, remains. The finding that there was no effect of cadmium exposure on the unstimulated DNA synthesis measured at 5 days in the MLC also supports this conclusion. (4) Cadmium exposure did not modify the response to allogeneic or syngeneic cells in a mixed lymphocyte culture. This conclusion is supported statistically as well as by examination of the distribution of individual animal responses.

Several alternative methods are available for the analysis of the results of the LTT, but none were felt to provide additional information or reduce the animal to animal variability. When the mitogen-induced lymphocyte transformation is expressed as a stimulation index (SI), the changes associated with cadmium exposure follow the same pattern as that of gross cpm although none of the differences are statistically significant (Table 1). The use of the SI is based on the assumption that, in normal individuals, the magnitude of the mitogen-induced response is related to the magnitude of the background response and that dividing by the background incorporation will normalize the mitogen response. However, many authors (Jensen et al., 1981; Burford-Mason and Gyte, 1979) have pointed out that presentation of data as stimulation indices gives undo weight to the unstimulated response. In the present study, there was no correlation between the values of unstimulated and mitogen-stimulated ^{3}H-TdR incorporation. Therefore, presentation of the data of this study as stimulation indices only compounds the problems associated with the animal to animal variability.

Several other studies of the effect of cadmium exposure via drinking water on murine lymphocyte transformation have been reported although it is difficult to compare studies since strain of mouse, cadmium concentration and length of exposure are all important factors in determining the effect of cadmium. Koller et al. (1979) found that 3, 30 and 300 ppm cadmium had no effect on the Con A response of CBA splenocytes while exposure to 30 and 300 ppm (but not 3 ppm) cadmium resulted in a statistically significant enhancement of the LPS response. This is in agreement with our finding of an enhanced LPS response in the 10 ppm treatment group. Gaworski and Sharma (1978), using a small number of animals per treatment group (4 or less), reported that exposure of mice to 160 ppm cadmium in drinking water depressed the response of splenocytes to both PHA and Pokeweed mitogen. Koller and Roan (1980) have reported that exposure to 3, 30 and 300 ppm cadmium tends to enhance the response of DBA splenocytes to allogeneic cells in the MLC although this enhancement was not statistically significant.

The mechanism by which cadmium exposure affects the lymphocyte response to mitogens may involve a change in the distribution or reactivity of specific lymphocyte subpopulations in the spleen. Koller and Brauner (1977) have demonstrated a decrease on the percentage of EAC-rosette forming cells in mice exposed to 30 or 300 ppm cadmium suggesting a decrease in the number of splenic B-lymphocytes as a result of cadmium exposure. This finding does not explain the increased response to the B-cell mitogen, LPS, and suggests that cadmium acts by enhancing the cellular response to stimulation. It is unclear whether this effect is a generalized phenomenon or specific to certain lymphoid populations. However, the fact that cadmium exposure does not affect the response to stimulation by allogeneic cells suggests that there

may be specificity in the action of cadmium.

The results of this study suggest that low levels of cadmium exposure, over a relatively short period of time, affect the lymphocyte response to both a B- and a T-cell mitogen. This finding is particularly significant since the cadmium exposure was at levels around and including that presently allowed in drinking water in the United States (0.01 ppm, Federal Register, 1975).

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Arlington, VA 22217

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In recognition of his contribution to psychopharmacology and, in particular, his researches on psychoactive drug use in depressed, geriatric, and anxious patients.

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In recognition of his contributions to social psychology and, in particular, his research on the achievement norms, organizational behavior, and status attainment of different social groups.

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In recognition of his contribution to microbiology and, in particular, his research on hepatitis and immunology.

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In recognition of his contributions to how ammonia affects toxicity in fish. This same mechanism may have broader application toward resolving how metabolic ammonia is detoxified in humans with impaired hepatic function.

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In recognition of his conceptual understanding, development, and contribution to biotechnology and, in particular, his ideas for

new materials and devices that could be made using genetic engineering.

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In recognition of his contribution to the field of electrical engineering and, in particular, his leadership of research programs in artificial intelligence and signal processing.

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In recognition of her outstanding achievements as a woman in engineering and her personal contributions to the science education of young people.

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University of Maryland
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In recognition of her contributions to nutrition and, in particular for her research on mineral and vitamin concentrations as influenced by the diet for different human groups.

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